A HISTORY
OF
ENGINEERING

BY

A. P. M. FLEMING
C.B.E., M.Sc. (Tech.), M.I.E.E.

AND

H. J. BROCKLEHURST
M.Eng., A.M.I.E.E.

"Man is a Tool-using Animal. Nowhere do you find him without Tools; without Tools he is nothing with Tools he is all."

Sartor Resartus.

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PREFACE

THE multitudinous applications of engineering at the present time must be evident to everyone, for these applications, covering as they do transport by rail, road, sea, and air, communication by telegraph, telephone, and radio, the means of obtaining the products of the earth and the motive power that drives all the machinery of production, have become commonplaces.

It is well known that even a century ago the amenities that engineering science has bestowed were not available, yet a close examination of conditions reveals the fact that probably in every age engineering in some form has been one of the fundamental means by which civilization has advanced. It has been impossible to enter in detail into the modern aspects of engineering in all its different phases, but in this book an attempt has been made to show in proper perspective the development of engineering down through the ages, in order to indicate its place at each period. At the same time, it has been the authors' purpose to show how rapid and extensive has been this development, and from this to suggest that the progress of engineering in the future will be not less marked than in the past.

In the preparation of the book the needs of students of industrial history have been borne in mind particularly, but it is hoped that its readers will be gathered from a wider field, and include all those interested in industrial affairs.

The authors desire to express their thanks to Miss A. Bennie for her assistance in reading the proofs.

A. P. M. FLEMING.
H. J. BROCKLEHURST.

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PART I

INTRODUCTION

THE history of engineering can be regarded as coincident with the history of civilization. Man has been described by Carlyle* as a tool-using animal, and his gradual evolution from barbaric savagery to his present developed condition has been brought about in no small measure by his capacity to fashion tools which have given him power to use the vast forces of nature for his own purposes.

It is well, however, before undertaking a historical review of the development of engineering tools and methods, to explore the meaning of the term "engineering." One of its most comprehensive definitions is contained in the Charter, dated 1828, of the Institution of Civil Engineers, where engineering is described as the "art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states, both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation, and docks for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters, and lighthouses; and in the art of navigation by artificial power for the purposes of commerce; and in the construction and adaptation of machinery; and in the drainage of cities and towns." This definition relates only to civil engineering, for up to comparatively recent times civil engineering was synonymous with the unqualified term "engineering." It is only since the Industrial Revolution that there has been specialization, and that the many widely different branches

* Carlyle, *Sartor Resartus.*

of engineering have been developed. In early times the practice of engineering was directed to two main purposes—firstly, convenience; and, secondly, preservation and protection; hence we find the early two-fold division of civil and military engineering.

The first branch of engineering to be recognized as separate from civil was mechanical engineering, which relates to steam engines and machine tools. The more important of the branches which soon afterwards came into being are mining engineering, which relates to devices for working iron ore, coal, and other minerals; sanitary engineering, dealing with water-supply and the disposal of sewage and other refuse; marine engineering, relating to the design and manufacture of engines for ship propulsion; naval architecture, which relates to the design of ships; gas engineering, relating to the manufacture and distribution of gas, whether for illuminating or power purposes; chemical engineering, relating to the manufacture of chemical products; electrical engineering, relating to the manufacture of electrical products and to the generation and distribution of electrical energy; and aeronautical engineering, relating to the manufacture and design of machines for aerial navigation.

CHAPTER I

ANCIENT ENGINEERING

THE knowledge derived from archæological research of engineering devices which existed prior to the beginning of recorded history is of a very scanty character. The story of prehistoric man can be gleaned from the crude pictures and other markings which have been discovered on rocks and the walls of caves; and from pictorial records and ancient remains it is possible to form some opinion of the tools and devices which were known to our progenitors of early times. It is customary in speaking of prehistoric times to refer to a Stone Age, a Bronze Age, an Iron Age, according to the material which was most prominently used for tools and weapons, but a more correct division has been suggested* on the following basis: first, an Early Palæolithic Age of vast duration; secondly, a Later Palæolithic Age that lasted but a small part of the first period; and thirdly, an Age Cultivation, being the age of white men in Europe, which began some ten or twelve thousand years ago, of which the Neolithic Period was the beginning, and which still continues.

The evidences of the Early Palæolithic Age are flints and stones shaved so as to be held in the hand, and probably used as hand axes. The people of this period probably employed also a variety of wooden tools, but of these, as is to be expected from the nature of this material, there are no relics. In the history of the Later Palæolithic men, archæologists distinguish three main stages—the Aurignacean, the Solutrian, and the Magdalenian. The implements of the first stage are well made, and show evidences of a rapid development of art. The fine stone implements of the second stage are distinguished by their razor-like edges, as thin and almost as sharp as steel. In the third stage stone implements are smaller, and bone harpoons,

* Wells, *Outline of History*, 58.

spear-heads, needles, and the like were used. The Neolithic Age of man is characterized by the presence of polished stone implements, notably the stone axe, in which the head was perforated so as to be more securely fastened to the wooden handle. This tool was probably handled more widely for working wood than for fighting purposes. There is evidence that about six thousand years ago copper and bronze were known, and the discovery of these metals marks the beginning of a new advance in the development of civilization.

At this point reference must be made to the use of fire and methods of its creation, as without its assistance metal ore must have remained useless in the earth. Fire appears to have been known since the earliest beginnings of the race. Mason* analyzes the methods of fire making in the probable order of their invention, and suggests four means—namely, by sawing, by ploughing, by reciprocating motion, and by percussion. The first two methods, the result of rubbing two pieces of wood together across the grain and with the grain respectively, were apparently not developed. The third and simpler device makes use of a twirling or reciprocating motion of a rod of dry wood on a partly decayed and very dry lower piece. The efficiency of this device is greatly improved if a few turns of a string are wrapped round the spindle, when by pulling the string backwards and forwards a rapid motion is obtained—a mechanical contrivance known as a fire drill.† These methods were probably soon followed by the percussion method, in which fires were started by striking iron pyrites with a flint in the midst of dry dead leaves, when after a few sparks from the pyrites the leaves burst into flame. It is significant that "flints and pieces of pyrites are found in close proximity in palæolithic settlements near the remains of mammoths";‡ and this method of fire making is at present used by many primitive peoples. It was the presence of fire that unlocked the mineral wealth of the earth. Neolithic man first discovered and used native copper, hammering it into the required shape. Later he learned the art of smelting copper from its ore, and

* Mason, *Origins of Inventions*, 88 *et seq.*

† Some excellent illustrations of these early methods of fire making are given in Lord Avebury, *Prehistoric Times*, 447 *et seq.*

‡ Hopf, *The Human Species*, 316.

cast copper implements, using moulds made to the same shape as the earlier stone implements. Lord Avebury suggests that the Neolithic men discovered the secret of smelting by the chance putting of lumps of copper ore among the ordinary stones with which the fire pits, used for cooking purposes, were built. The fact that copper and tin-stone frequently occur together explains the discovery of bronze, which is an alloy of the two metals. Later, perhaps three thousand years ago in Europe, men began to smelt iron, and the dawn of the early Iron Age is dated from the time when the metal was adopted for weapons and tools of everyday use, bronze being retained for ornamental purposes only.

There are both written and material records of the engineering knowledge and skill of early civilizations. In the words of one authority: " Of the races to be considered, I will mention, in what seems to me to be their proper order of importance, Chaldea, Babylon, Egypt, Assyria, Etruria, Palestine, Moab, Persia, India, China, and the Incas. To this aggregate every form of engineering was known which did not require the application of the generated forces. These peoples built canals for transport and irrigation, reservoirs and aqueducts, docks, harbours, and lighthouses. They erected bridges of wood and stone, as well as suspension bridges, laid out roads, cut tunnels, constructed viaducts, planned roofs for their massive buildings; tested the strength and discovered the weakness of their building materials; instituted elaborate systems of drainage; planned fortifications; designed engines of attack and floating bridges; devised methods for the transport of heavy objects—in fact, covered to a greater or less degree all departments of hydraulic, bridge and road, sanitary, military, and mechanical engineering."*

Archæologists remind us that two factors need to be borne in mind in considering early engineering feats. In the first place, time has not to be taken into account, many years being spent in erecting colossal buildings and impressive monuments. In the second place, private enterprise was practically unknown, all large undertakings being worked upon by thousands of

* Watkins, " Beginnings of Engineering " in *Trans. Amer. Soc. of Civil Engineers* (1891), XXIV. 309.

workpeople, who were paid out of the public treasury. According to Herodotus, a tradition was current in his time that the Great Pyramid occupied a hundred thousand men for twenty years, and Petrie has shown that these numbers are quite credible. Again, thirty thousand men were engaged in the building of Solomon's Temple at Jerusalem.* These two factors explain in a measure the colossal scale of the buildings and other engineering triumphs of early civilizations, and the extraordinary attention that was paid to details of construction and to points of finish.

It is interesting to observe that the engineer architect held a position of power and influence in all ancient communities. "He was the adviser of the king, his ministers and his generals, and usually held a sacred office in addition to his secular duties. His burial was solemnized with pomp and display, and statues and other monuments were erected to perpetuate his memory. M. de Sarzec found a statue† at Telio, from the earliest period of Chaldean art (about 4000 B.C.), which holds upon its knees a tablet 'on which the plan of a fortress, with its bastions and posterns, is engraved in outline, just as an architect of the present day would draw it. A graduated rule—that is to say, one subdivided into fractions of unequal but proportional length, 10¾ inches long—is carved in relief beside the plan, for which it serves as a scale. Finally, at the side lies the style with which the architect engraved his design.' "‡ In Egypt, 3700 B.C., there also existed an officer, the "Superintendent of Works," who had charge of the construction and repairs of public edifices and roads.§ The authority for this fact is established by a wooden statue in the Bulak Museum, discovered at Sakkarah by Marietta Bey, which represents an official who bore the title of Superintendent of Works under the Fourth Dynasty.||

The outstanding witness of the engineering skill of early civilizations lies in the remains of their buildings in stone. Some of these are merely aggregations of huge masses of stone, given some geometric form of arrangement, the most notable

* 1 Kings V. 13. † Now in the Louvre.
‡ Babelon, *Manual of Oriental Antiquities*, 29.
§ Brugsch, *Egypt under the Pharaohs*, 121.
|| Maspero, *Egyptian Archæology*, 219, 220.

of which are the monuments at Stonehenge and Carnac, and the Pyramids of Egypt. At Stonehenge huge stones weighing individually many tons still stand erect, while a number of others lie around them. The stones at Carnac, in Brittany, are of two types—the dolmens, or tomb-stones, and the menhirs, or single pillars. The dolmens are all built on the same plan, and consist of several large upright stones capped by a huge slab. They originally formed the central chambers of burial mounds. The capstone of one tomb measures 28 by 14 feet, and is several feet thick, while another is a slab of stone 16 feet square. Equally striking are the menhirs: the fragments now existing of one of these upright pillars suggest that when built it must have risen some 67 feet into the air and have weighed over 350 tons. The Pyramids of Egypt are among the chief wonders of the world. The Great Pyramid has a base 764 feet square, and originally rose 480 feet into the air, exceeding the height of St. Paul's Cathedral, London, by 120 feet. The weight of this mass is measured at approximately 6,840,000 tons. Many of the individual stones weigh between 40 and 60 tons, and the granite blocks roofing over the central sepulchral chamber are nearly 19 feet long, from 3 to 4 feet deep, and 2 feet broad. The accuracy of work of the Great Pyramid is such that the four sides of the base have only a mean error of six-tenths of an inch in length, and twelve seconds in angle from a perfect square.

The methods adopted by these early civilizations for transporting and lifting such huge masses of stone have proved very puzzling. The old Assyrian sculpture in the British Museum gives a representation of a large number of slaves dragging a sledge on which reclines a massive stone bull. In front are men laying down wooden rollers, while others behind urge the sledge with levers. The great Temple of Diana, built at Ephesus about 600 B.C., had 127 columns, each 60 feet high and 7 feet in diameter, shaped from single blocks of marble. The architects, Chersiphron and his son Metagenes, moved these great masses eight miles from the quarries to the temple site by enclosing them in wooden frames and rolling them across country with the help of oxen. Herodotus tells us that an inclined road of polished stone was constructed from the banks of the Nile to the Great Pyramid, about three-quarters of a

mile, for transporting the blocks brought down the Nile from the "Arabian Mountain." He also mentions that ten years were spent in making this road, which, in his opinion, was a hardly less notable work than the building of the Pyramid itself.

An excellent illustration of the engineering skill of the Egyptian people is afforded by their methods of quarrying, transporting, and erecting the huge blocks of stone used for obelisks. In order to separate the huge blocks of stone from the native rock, a groove was cut to mark the outline of the stone required, into which groove frequent holes were bored for the insertion of wooden wedges. When the wedges had been firmly secured in place, the groove was filled with water, which caused the wooden wedges to swell and crack the granite throughout the length of the groove. Rollers made from the branches of palm-trees were used to push the stone forward to the banks of the Nile, where it was surrounded by a timber raft. With the rising waters of the Nile the raft floated and carried the obelisk to the point on the river where it was to be set down. Thousands of labourers then dragged the stone and pushed it on rollers up an inclined plane, where by the use of levers and ropes made of the date-palm, the obelisk was placed in its final upright position. "It speaks much for the mechanical accuracy of the Egyptian masons that so true was the level of the top of the base and the bottom of the long shaft that in no single instance has the obelisk been found to be out of the true perpendicular."* Similar methods of transporting and lifting huge blocks of stone are to-day used by primitive tribes—for instance, the Khasi hill tribes of India, who still erect megalithic monuments. "The slabs of sandstone are quarried near by where they are to be set up by means of wedges. Some of these weigh twenty tons. They are moved on a cradle made of strong limbs of trees, roughly smoothed and rounded so as to present little surface to friction. In dragging and setting up the slabs, all the members of a community are under an obligation to assist on such an occasion, and are not paid for their labour, receiving in the evening a little food or liquor at the dwelling of the family who sought the aid."†

* King, *Cleopatra's Needle*, 18.

† Austen, *Journal Anthrop. Institute* (1872), I. 127.

The ancients were not only familiar with the art of working huge masses of stone; they were equally skilled in the construction of buildings of brick. Probably the earliest reference we have to the use of brick is in the Book of Genesis,* which records that the Tower of Babel, erected in Chaldea, was built of brick. The Chaldean soil was specially suited to the requirements of the builder, for when moistened and baked in the sun it produced a brick of singular durability. The bricks found in the vaults at Ur, where it is recorded that Abraham once lived, are 12 to 16 inches square and 3 to 4 inches thick. Egyptian bricks were also longer than those to which we are accustomed, those among the mines at Memphis measuring 15 inches in length, 7 in width, and 4¾ in thickness. "The larger works of the Babylonians are composed mainly of bricks, the interiors of the walls being sun-dried, the exterior layers being small and kiln-dried. In the ruins of Khorsabad are found walls of sun-dried bricks faced with stone. These walls were noted for their size more than for engineering skill in construction. Some of these bricks have lasted so well that the ruins of Mesopotamia have furnished materials for many edifices in modern Persia; and the stamp of Nebuchadnezzar is not uncommon in the walls of brick buildings constructed during the last two centuries and inhabited at the present time. One of the bricks bears an inscription which, translated, reads: 'Nebuchadnezzar, King of Babylon, Restorer of the Pyramid and the Tower, eldest son of Nabopolassar, King of Babylon.'"†

The remains which have been discovered, combined with contemporary evidence, enable us to form a fairly accurate estimate of the tools which the ancients used in the undertaking of their engineering works. The principles underlying ancient tools do not differ from those of our present-day tools, although, as is to be expected, very considerable development has taken place in the actual form of the tool. The principal tools of the ancients were saws, drills, and lathes, and probably the Egyptian was the earliest civilization which applied these

* Genesis XI. 3 and 4: "And they said one to another, Go to, let us make brick, and burn them throughly. And they had brick for stone, and slime had they for mortar." The slime alluded to here was bitumen —a petroleum earth similar to that now found in the vicinity of the Dead Sea.

† Watkins, *op. cit.*

tools on any large scale. Professor Flinders Petrie, who undertook extensive research respecting the tools used in the construction of the Pyramids, writes:* "That the blades of the saws were of bronze we know from the green staining on the sides of saw cuts and on grains of sand left in a saw cut. The straight saws varied from 0·5 to 0·2 inch thick, according to the work; the largest were 8 feet or more in length, as the cuts run lengthways on the Great Pyramid coffer, which is 7 feet 6 inches long. Next, the Egyptians adapted their sawing principle into a circular instead of a rectilinear form, curving the blade round into a tube, which drilled out a circular groove by its rotation; thus, by breaking away the cores left in the middle of such grooves, they were able to hollow out large holes with a minimum of labour. These tubular drills vary from $\frac{1}{4}$ to 5 inches in diameter, and from $\frac{1}{30}$ to $\frac{1}{5}$ inch thick. A peculiar feature of the cores is that they are always tapered, and the holes are always enlarged towards the top. In the soft stones cut merely with loose powder, such a result would naturally be produced simply by the dead weight on the drill head, which forced it into the stone, not being truly balanced, and so always pulling the drill over to one side; as it rotated this would grind off material from both the core and the hole. But in the granite core such an explanation is insufficient, since the deep cutting grooves are scored out quite as strongly in the tapered end as elsewhere; and if the taper was merely produced by rubbing of powder, they would have been polished away, and certainly could not be equally deep in quartz as in felspar. Hence we are driven to the conclusion that auxiliary cutting points were inserted along the side as well as round the edge of the tube drill; as no granite or diorite cores are known under 2 inches diameter, there would be no impossibility in setting such stones, working either through a hole in the opposite side of the drill or by setting a stone in a hole cut through the drill and leaving it to project both inside and outside the tube. Then a preponderance of the top weight to any side would tilt the drill so as to wear down the groove wider and wider, and thus enable the drill and the dust to be the more easily withdrawn from the groove. The principle of rotating the tool was, for

* Petrie, *The Pyramids and Temples of Gizeh*, 174.

smaller objects, abandoned in favour of rotating the work, and the lathe appears to have been as familiar an instrument in the Fourth Dynasty as it is in modern workshops. The diorite bowls and vases of the Old Kingdom are frequently met with and show great technical skill. One piece found at Gizeh shows that the method employed was true turning, and not any process of grinding, since the bowl had been knocked off its centring, recentred imperfectly, and the old turning not quite turned out; thus there are two surfaces belonging to different centrings and meeting in a cusp. That no remains of these saws or tubular drills have yet been found is to be expected, since we have not yet found even waste specimens of work to a tenth of the amount that a single tool would produce; and the tools, instead of being thrown away like the waste, would be most carefully guarded. Again, even of common masons' chisels, there are probably not a dozen known; and yet they would be far commoner than jewelled tools, and also more likely to be lost, or to be buried with the workman. The great saws and drills of the Pyramid workers would be royal property, and it would perhaps cost a man his life if he lost one; while the bronze would be remelted, and the jewels reset, when the tools became worn, so that no worn-out tools would be thrown away."

Early lathes were of two types, known respectively as the bow and cord lathe and the pole lathe, with which a backward and forward rotary motion was obtained. The pole lathe is described as " a long elastic pole fixed at one extremity to the ceiling, and at the other attached to a cord which is coiled once or twice round the body to be turned, or round a pulley which carries that body along with it, and then passes on to the treadle, to which the lower end of it is fastened."* For small work the two ends of the cord were fastened to the two ends of a bent rod resembling a bow, so that one hand operated them both. This convenient device was used by the Egyptians. In precisely the same way drills must have been actuated by cord round the drill spindle.

Tunnels are among the earliest important engineering works of man, and in the primitive history of the race were adopted for dwellings and tombs, then for quarrying and mining, and

* Smith, *Panorama of Science and Art*, 66.

finally for water-supply, drainage, and other requirements of a more advanced civilization. The oldest inscription in the world, dated the tenth century B.C., relates to a tunnel built for the purpose of water-supply. It appears on the Moabite Stone now preserved in the Louvre, and concludes an account of the successful rebellion of Mesha, King of Moab, against Israel, with the words: "Mesha built two conduits, and since no cisterns were in the city, Karcha, Moab, he ordered the inhabitants of the city to place a cistern in each house. He then had a conduit constructed by the Israelitish prisoners to supply water to the cisterns." A very ancient tunnel has been discovered in Judea, by which water was brought from the Virgin's Pool in the Kedron Valley to the Pool of Siloam. An inscription engraved inside the tunnel gives an account of the engineering difficulties encountered in the course of its construction, and it states that the two culs-de-sac where the excavations overlapped were due to lack of engineering skill. The engineering ability of the Etruscans is evidenced by the subterranean tombs and tunnels which they built, and some of the latter, constructed several centuries before the foundation of Rome, are not only still extant, but working with efficiency. It has been said* that "they drained lakes by cutting tunnels through the heart of mountains, and diverted the courses of rivers to reclaim low and marshy ground, just as the Val di Chiana has been rescued in our own time." The emissary of Lake Fucinus is a conspicuous example of a Roman tunnel, made without the use of explosives. It was designed by Julius Cæsar and executed by Claudius, and was more than 3 miles in length. For more than a mile it passed under a mountain, whose summit is over 1,000 feet above the level of the lake. The bore was carried over thousands of feet through cornelian so hard that every inch was worked with a chisel. Within the city and adjoining areas of Rome there were originally 250 miles of aqueducts, about 50 miles of which were supported on stone arches. Frontinus, who was surveyor of aqueducts during the reign of Nerva (A.D. 97), wrote a work giving in close detail engineering information relating to the construction of Roman viaducts. From these details Mr.

* Dennis, *Cities and Cemeteries of Etruria*, I. 60.

Parker, the English engineer, estimates the total amount of water delivered by these aqueducts to be equal to a stream 20 feet wide by 6 feet deep constantly pouring into Rome—a volume equivalent to over 300,000,000 gallons per day.

The Roman engineer-architect Vitruvius makes numerous references in his treatise on architecture to engineering devices of his time, and shows, *inter alia*, that the Romans were familiar with the use of high pressure mains for water transmission, and also with schemes embodying the principle of the syphon for negotiating a valley. A pipe syphon backed with concrete that would withstand a head of 340 feet of water has been discovered at Alatri in Italy. The Romans constructed many lighthouses. Claudius built one at Ostia, then the chief port of Rome, and Pliny records their existence at Ravenna, Poggiola, and Messina, and also one at Capri, which was destroyed by the earthquake that preceded the death of Tiberius. Remains of Roman engineering are to be found in many lands, and practically every country that was conquered by the Romans possesses some evidence of their engineering skill. A notable Roman aqueduct in France, originally constructed to supply water to the Imperial Palace at Lugdunum, the modern city of Lyons, leads from a stream, the Gier, at the foot of Mount Pila, to the summit of Fourvières. It terminated in a stone reservoir lined with cement, in the walls of which are eight elliptical holes 12 inches high by 9½ inches wide. Eight lead pipes descended from these holes into the valley, and were carried across the bottom of the stream on an aqueduct bridge 25 feet wide. Some of these pipes were found in a vineyard near the top of Fourvières in the early part of the eighteenth century, and were described by Columbia in his *History of Lyons*. Perhaps the most important engineering remains in conquered Roman lands are the remains of Roman roads, many of which are to be found in England. There is evidence to show that in the making of their roads the Romans followed no hard-and-fast rule, but adapted the construction according to the situation and the materials available. In general, a good class Roman road consisted of a shallow trench about 3 feet deep and 18 feet wide, the bottom of which was hardened by hammering, filled with successive layers of large

flat stones, smaller stones, and a course of concrete, and finished with a surface of accurately jointed flat stones sloping slightly from the centre to the sides of the road in order to throw off the water. Speaking of Stane Street, Surrey, Manning says: "The Rector of Ockley lately dug entirely through the Causeway in his glebe land to make a ditch, and found it about four feet and a half thick, formed of several rows of flints and other stones laid alternately and bedded in sand or very fine gravel and laid with the utmost regularity and neatness."* Stukeley found part of Ermine Street, north of Huntingdon, still paved, and describes the paving of the Fosse road, south of Ilchester, as consisting of the "flat quarry stone of the country, of a good breadth laid edgeways, and so close that it looked like the edge of a well fallen down."†

The use of fire and the probable chance discovery of the metallurgical art in prehistoric times have been touched upon. Early civilizations improved the processes of manufacture, and found new uses for metal in their engineeering works. Bronze tools were used in the construction of the Pyramids of Egypt. The Book of Genesis‡ refers to the existence of brass and iron in Assyria, and the Chaldeans could work as skilfully in bronze as in stone. At Tello, M. de Sarzec found remains of doors that turned on pivots supported in cavities in stone blocks. "To prevent the wooden pivot of the doors from wearing out too rapidly, it was enveloped in a metal (bronze) sheath that took the form of a funnel, and which was fixed to the wood by nails."§ From the sharpness of many ancient coins it is evident that the die sinker was not only able to work in hard metals, but possessed distinct mechanical ability in the construction of the presses by which the coins were struck.

The Greeks were familiar with the use of iron 600 years before the Christian era, although they still continued to make their shields and weapons of bronze, and "iron was so rare and valuable that sufficient for the production of a ploughshare was bestowed as a prize upon the winner of their annual games."|| Aristotle gives an account of the Greek method

* Manning, *History of Surrey* (1814), III., Appendix XI. (vii.)
† Stukeley, *Itinerarium Curiosum.*
‡ Genesis IV. 22: "An instructor of every artificer in brass and iron."
§ Babelon, *Manual of Oriental Antiquities*, 18.
|| Turner, *Metallurgy of Iron*, 5.

of making steel in the fourth century B.C., proving them to have been also acquainted with the art of melting iron: "Wrought iron itself may be cast so as to be made liquid and to harden again; for the scoria of iron subsides and is purged off by the bottom; and when it is often defecated and made clean, this is steel. But this they do not often because of the great waste, and because it loses much weight in refining; but iron is so much the more excellent, the less recrement it has." In the days of the Romans iron was used for hinges, locks, and similar purposes; "their shields were rimmed with iron and had a central boss of the same metal, their spears were pointed with iron and their swords were of steel. They used steel also for their axes, saws, chisels, and other tools."*

The early records of the uses of iron in this country are very meagre. The ancient Britons used the metal for mining and for agricultural purposes; swords and other weapons, including the scythes which they attached to the axles of their chariots, were also made of iron. "Iron bars were used as currency; these bars were about 2 feet 7½ inches long, and have often been found secreted in a manner suggestive of a hoard of coins."† The coins were spindle-shaped, probably to enable the owner to convert his money into swords. Whatever degree of skill the Britons attained in iron working had probably been acquired by contact with Phœnician and Greek traders who came to this country to barter for tin during a period extending over many centuries before the Roman invasion. The Romans naturally made use of the iron deposits of Britain during their occupation of this country. The Emperor Hadrian established an arms factory and forge at Bath in A.D. 120. The ore was obtained from South Wales, Forest of Dean, and Yorkshire, and the Forest of Dean mines were worked until the year 409. The Roman methods of smelting, like all the early iron-smelting processes, were crude and wasteful, and the enormous quantities of slag left behind in the neighbourhood of the Forest of Dean ironworks were the sources from which the iron works in the district obtained a large part of their new material from the middle of the seventeenth century onwards.

* Jeans, *History of the Iron and Steel Industry*, 10.

† Brough, "The Early Use of Iron" in the *Journal of Iron and Steel Institute* (1906), I. 247.

CHAPTER II

THE HISTORY OF MEASUREMENT

AT each stage in the evolution of engineering, improved knowledge of scientific principles and characteristics of materials has been accompanied by improved methods of measurement. A means for accurate measurement has been one of the most important factors in engineering development, and the requirements in this respect are so exacting that a system of measurement has been devised essentially different in its detailed application from the ordinary measures in daily use for social and economic purposes. While the units of weights and measures are the same in every department of life, the engineer probably uses the greatest variety of subdivisions of these units with ever-increasing refinement of accuracy.

There is little doubt that in the earliest days of the race units of measurement of length were furnished by the human body, probably because they were the most accessible. Evidences that remain of the life and customs of the ancients show that such expressions of length as the forefinger, the span of the extended fingers, of the foot, the arm, and the distance between finger-tips with arms outstretched, were all included in the commonly accepted standards. As examples of natural units might be cited the measures devised from the human body which readily connect themselves one with another by certain relations.* Thus:

The digit	= 1	part.
Palm or handbreadth	= 4	parts.
Span	= 12	,,
Foot	= 16	,,
Cubit	= 24	,,
Step or single pace	= 40	,,
Double pace	= 80	,,
Fathom, or distance between extended arms	= 96	,,

* Hallock and Wade, *The Evolution of Weights and Measures*, 6.

In fact, to-day, natural measures of this order are still used where artificial measures are not available. The pace of a man is supposed to equal one-half of his stature, the cubit one-fourth, the foot one-sixth, and the span one-eighth. The hand is reckoned one-third of the foot, and the breadth of the thumb, one-twelfth.

The obvious defect of such natural standards of measurement is their lack of uniformity. As soon as groups of men came together for purposes of barter, the varying standards of length consequent upon their referring, for example, the "arm's-length" of cloth to the length of their own arm would result in embarrassing situations, and would retard rather than facilitate trading. The immediate solution of the difficulty would be the acceptance of an agreed standard of length, such as the length of the span, forearm, etc., of the chieftain of a tribe, or king of the country. Tradition has it that in this country, so late as the time of Henry I., the English yard was fixed by the length of the sovereign's arm. It is worthy of note that the Anglo-Saxons made distinct efforts to secure uniformity in weights and measures, by enacting legislation affecting them.* William the Conqueror recognized the Anglo-Saxon standards, and endeavoured to preserve them by decreeing that the measures and weights should be true and stamped in all parts of the country, as had before been ordained by law. "The unit of length was the yard or gird, which was identical with the ell, and as late as the reign of Richard II. (1377–1399) the words 'virgu' or 'verge' (yard) and 'ulna' or 'aulore' (ell) are found in the laws and official documents in Latin or Norman French, as the case may be, to denote the same unit of length."

"In addition to the purely Saxon measures there were those

* Bishop Fleetwood, *Chronicon Preciosum* (1745), 27: "It was a good law of King Edgar that there should be the same money, the same weight, and the same measures, throughout the Kingdom: but it was never well observed. What can be more vexatious and unprofitable, both to men of Reading and Practice, than to find that when they go out of one country into another, they must learn a new language or cannot buy or sell anything. An acre is not an acre; nor a bushel a bushel if you travel but ten miles. A pound is not a pound if you go from a goldsmith to a grocer, nor a gallon a gallon if you go from the alehouse to the tavern. What purpose does this variety serve, or what necessity is there, which the difference of price would not better answer and supply?"

which had been brought by the Romans, and which, though not corresponding with Saxon measures, had survived and become assimilated with the older measures. Among these were the mile, corresponding to the Roman millia passuum, the inch and the foot, which soon became recognized as purely English measures and to have their own fixed values. Then, in addition, when the Belgic tribes migrated to Britain they brought the Belgic foot of the Tungri, which was $\frac{1}{8}$ longer than the Roman foot, and was used until the fifteenth century. The average length of this foot was 13·22 inches, according to modern measure, and a yard of three such feet would be 39·66 inches, which would correspond most closely to the metre of to-day, which is equivalent to 39·37 inches. Such a yard existed and was known as the yard and the full hand, and eventually was suppressed by law in 1439. This was extremely unfortunate, as had this yard been retained it would have ensured a correspondence with the French metric system without the slightest difficulty."* During the reign of Richard I. legislation was enacted whereby standards of length should be constructed of iron, and measures of capacity with brims of iron, and suitable standard measures kept by the sheriffs and magistrates. It does not appear, however, that this law was enforced.

Few changes have taken place in the standard of length since the period of the Anglo-Saxons, the surviving standards of the time of Henry VII. and Elizabeth not varying by more than a hundredth of an inch from the present imperial yard. "In fact, we find the Anglo-Saxon measures of length perpetuated on the same basis as is given in the Statute of Edward (17 Edward II., 1324), where there is a restatement in statutory form of what has since become the well-known rule that three barley-corns, round and dry, make an inch, 12 inches a foot, 3 feet a yard (ulna), $5\frac{1}{2}$ yards a perch, and 40 perches in length and 4 in breadth an acre."† Throughout, the Roman duodecimal system of subdivision was adopted, whereby the foot is divided into twelve equal parts.

The earliest English standard of length, the Exchequer standard yard of Henry VII., constructed in 1496, was a brass

* Hallock and Wade, *op. cit.* 31. † *Ibid.*, 36.

of octagonal section, divided into inches and also into sixteen equal parts. This standard was replaced in 1588 by the Elizabethan standard yard, also of brass, but rectangular in section. With the standard yard of 1588 there is also "an ell rod of 45 inches (exact length 45·04 inches), and a bar with a bed or matrix for both the yard and the ell rods, but such an ell, which doubtless corresponded to the French measure of cloth, does not appear in any statute." The standard yard of 1588 served as a standard until the nineteenth century, despite the fact that about the year 1800 it was broken and had to be mended with a dovetail joint. The next step in the development of English standards was taken in 1758, when a Committee of the House of Commons was appointed "to enquire into the original Standards of Weights and Measures in this Kingdom and to consider the Laws relating thereto." The Committee prepared a standard yard, which has been described as "the first scientifically constructed measure of length in this country."* The following is an extract from their report: "Your Committee being informed that in the year 1742, several Members of the Royal Society were at great pains in taking an exact measure of these standards, by very curious instruments, prepared by the late ingenious Mr. Graham; and that the Royal Society had a brass rod made pursuant to their experiments; your Committee applied to the Royal Society for inspection of it: and it being readily communicated, your Committee compared it with the standard in the Exchequer, and examined Mr. Harris, who said that a lineal or longitudinal measure should be the standard of all measures of capacity; and as the law seemed already to have made the yard the standard, he thought, that to prevent variations, it should be a clean straight brass rod, of about thirty-eight or thirty-nine inches long, and about an inch broad or thick; near each end of this rod, a fine point should be made, and a fine line drawn through it at right angles to the sides of the rod; the distance between the said two points to be the true standard length of the yard; and as the edges of points made in brass were liable to decay, he would recommend two gold studs or pins, to be

* Chrisholm, *Seventh Annual Report of the Warden of the Standards* (1872, 3), 25 and 34.

fixed in the brass rods, or where the points were to be made which ascertain the length of the yard. This rod should be fitted in a proper box, and placed in safe custody, to be used occasionally; but that for the ordinary sizing of yards, there should be another rod made, in the same manner as the former, only it should have two upright fixed cheeks; by these cheeks, anything placed between them might be more readily and exactly measured than by the standards now at the Exchequer; and the standard yard being once fixed, the legislature need only declare what proportion an inch, foot, perch or mile bears to this standard; and in like manner, declaring how many square perches make an acre, and the like, there will be exact standards for all those kept in the Exchequer. And he observed, that the rods of the Exchequer, and that of the Royal Society were rather too small, but the Royal Society's standard was made so accurately, and by persons so skilful and exact, that he did not think it was easy to obtain a more exact one; and therefore, he humbly advised a comparison to be made by the Committee and submitted whether the Committee would think proper to have a rod made in consequence of that comparison for security. Your Committee thought it was necessary to pursue Mr. Harris's thought, and therefore had two rods made by Mr. Bird, according to Mr. Harris's proposal; and having these rods, together with that of the Royal Society laid in the same place, at the receipt of the Exchequer, all night, with the standards of length kept there, to prevent the variation which the difference of air might make upon them, they, the next morning, compared them all, and, by means of beam comparisons brought by Mr. Bird, found them to agree as near as it was possible. The rods which they had thus prepared, were sealed up by your Committee, and are herewith laid before the house to be disposed of as shall be thought most proper. That which your Committee thinks should be the proper standard, if the Legislature shall think fit to make it so, and carefully preserved, is marked thus 'Standard Yard, 1758,' and the other with the cheeks, is what your Committee would propose to be kept at the receipt of the Exchequer for common use, and is divided into three equal parts, each of which is consequently a foot; one of these third parts into twelve, making inches,

and one inch into ten equal parts, for the easier adjusting of any comparative measure."*

The standard yard recommended by the Committee was legally adopted as the standard of Great Britain by an Act of Parliament passed in 1824, and served as standard until destroyed by the fire which, in 1834, consumed the Houses Parliament. The next standard yard was prepared under the direction of a Parliamentary Committee appointed in 1843, and was legalized in 1855 by the Standards Acts, which was ratified in 1878 in the Weights and Measures Act. This is the present standard yard of Great Britain, and its construction may therefore be briefly described.† "The Imperial standard yard is a solid square bar of a special bronze or gun metal known as Bailey's metal, composed of copper 16 parts by weight, tin 2½, and zinc 1. It is 38 inches in length, with a cross-section 1 inch square, and has near its ends two circular holes or wells sunk to a point, midway in the depth of the bar. In these wells are inserted two gold studs, on which the fiducial lines are engraved, the distance between them forming the imperial standard yard of 36 inches at a temperature of 62° F. This imperial standard is preserved in a strong fireproof room at the Standards Office in Old Palace Yard, Westminster, and copies are deposited at the Royal Observatory, Greenwich, the Royal Mint, the Royal Society, and the Houses of Parliament. The latter are specially designated by statute as Parliamentary copies, and must be compared with the imperial standard once every ten years, since in the event of the possible destruction of the latter, they would furnish the source from which a new standard would be derived. There were in addition thirty-five other standards made of the same size and the same material, which were fully compared with the prototype and were distributed to the various nations of the world and to scientific institutions in Great Britain and elsewhere."‡

Up to recent times it has been commonly supposed that if by some mischance all these bars had been lost or destroyed,

*Quoted by Kelly, *Metrology*, 59, 60.

† For full account, see Airey, "Account of the Construction of the New National Standards of Length, and of its Principal Copies," in the *Philosophical Transactions of the Royal Society*, June 18, 1857.

‡ Hallock and Wade, *op. cit.*, 246, 247.

the ultimate basis of a system of measurement would have been lost in consequence. However, even as far back as 1824, it was provided in the Act which legalized the Bird standard that reference should be made, in the event of the loss of the standard yard, to a pendulum beating seconds in a vacuum at the latitude of London and reduced to sea-level, which would have the relation to the yard of 39·1393 to 36. This provision was made use of when the standard yard was destroyed by fire ten years later. But recently another national standard of length has been determined. Scientists have perfected an apparatus in which the wave lengths of certain kinds of monochromatic light can be measured, and duplicated, and it thus becomes possible to build up, *de novo*, the standard yard. The credit for most of this work is due to Professor A. A. Michelson, who carried out his researches at the International Bureau of Weights and Measures,* and who had previously accurately determined the velocity of light.

The social and economic benefits accruing from the establishment of a uniform system of measures have been incalculable, and have facilitated the commercial intercourse between nations which now takes place on so great a scale. At the same time the establishment of the British standard of length, with its subdivision of feet and inches, marks but the starting-point of real engineering achievement. As the basis of modern engineering is the principle of fine measurement, errors involving thousandths, ten-thousandths, and even millionths of an inch have to be reckoned with and eliminated. The need for extensive subdivisions of the inch for engineering purposes was first fully appreciated by Sir Joseph Whitworth, a brief review of whose life and work reveals the importance of his contribution to the engineer's art. Born in Stockport, near Manchester, on December 21, 1803, Joseph Whitworth was educated at home by his father until he reached the age of twelve years, when he was sent to a private academy near Leeds. His stay at school was short, for after eighteen months there he entered, at fourteen years of age, his uncle's mill in Derbyshire.

* Michelson, "Détermination expérimentale de la valeur du mètre en longeurs d'ondes lumineuses," *Travaux et Memoires*, XL. (Paris: Bureau International des Poids et Mesures).

After four years he discarded mill-life in favour of workshop training. The distinction which attended his four years' training as a mechanic in a Manchester workshop made it clear that Whitworth was to devote his life to engineering work. He was quick to gauge the limits of achievement possible with the few and simple tools which at that time formed the stock-in-trade of the mechanic, and which were in effect a hammer and chisel, file, and simple lathe and screw-cutting machine. The standard of measure was the 2-foot rule, divided into 16ths and 32nds. True the more skilled mechanics worked to rather finer limits which were purely empiric, and were known as 32nds, bare 32nds, and full 32nds, but the very crudity of these measures and the variety of results that were produced among individual craftsmen meant that only simple work could be undertaken with any measure of average accuracy.

At twenty-one years of age Whitworth went to London to enter the works of Maudslay and Clements, toolmakers, who provided him, during the eight years he was in their employ, with an invaluable training in the highest branches of mechanical work, as it was then practised, a training which enabled him in later years to undertake personally the construction of delicate pieces of measuring machinery which demanded the highest grade of mechanical skill. While working with Maudslay and Clements, Whitworth recognized the need for improved machine tools in order to cheapen engineering processes. He first directed his attention to the production of a true plane, as this constitutes the basis of all machine tool construction. Before any progress could be made the old method of producing planes had to be superseded by one involving mechanical precision. Whitworth described the old process in a paper before the British Association in Glasgow, 1840. The method of producing true planes was that of grinding the surfaces of plates alternately with emery powder and water. In the course of his paper Whitworth wrote: "Grinding was objectionable because it was unreliable. If one plane was true and the other not, grinding might give part of the error to both instead of the true plane being imparted to each. Moreover, grinding powder collected in greater quantity above the edges of the metal than in the interior part, producing untrue planes." The method

of making a surface plate where there was already a model consisted in smearing the plate to be prepared with a thin film of colouring-matter, and then rubbing it with the true plate. Wherever the true plate rubbed off the colour, a high spot on the plate to be prepared was indicated, and the mechanic laboriously scraped away the high spot and repeated the trial. In 1830 Whitworth by means of a straight edge and scraper succeeded in originating his first true plane. After this he constructed his planing machine, consisting essentially of a true plane as the table of the machine sliding in two long grooves, the latter being true planes, with which copies of the true plane could be made cheaply and in great number. So exactly could surface plates be made by this method, that "if one of them be placed upon another when clean and dry, the upper one will appear to float upon the lower one without being actually in contact with it, the weight of the upper plate being insufficient to expel, except by slow degrees, the thin film of air between their surfaces. But if the air be expelled, the plates will adhere together, so that by lifting the upper one the lower will be lifted along with it, as if they formed one plate."* The Whitworth planing machine made possible, at the time of its invention, a new degree of precision on all types of engineering products then in use that depended on sliding motion of surfaces—such, for instance, as the valves of steam engines—and provided true surfaces for the tables of printing presses and for stereotype plates.

In 1833 Whitworth left London and returned to Manchester, where he began business on his own account in a humble way. On the door of his shop was written "Joseph Whitworth, toolmaker, from London," and this enterprise marked the beginning of a works which to-day is world-wide in reputation. He next turned his attention to the improvement of the screw. At that time no uniformity existed among manufacturers respecting the relation between type of thread and diameter of screw. Great inconvenience resulted, for screws were not interchangeable, and whenever machines required repairing special screws had to be manufactured to resemble those which the manufacturer had originally constructed. Whitworth

* Jeans, *Creators of the Age of Steel*, 221.

made a collection of screwed bolts from the larger workshops of the country, and determined from these an average thread for each diameter. Screw threads by this method were fixed for $\frac{1}{4}$, $\frac{1}{2}$, 1, and $1\frac{1}{2}$ inch diameters, and these formed the principal points on a scale by which intermediate and outside sizes were determined. His next step was to improve the guiding screw on the ordinary lathe, so that screw threads could be readily cut, and by his own labour he made a guiding screw 30 feet long, with two threads per inch, which took him six weeks to perfect. The lathe adapted with this mechanism provided the standard for the manufacture of the Whitworth screw thread, a standard which has since been adopted through the whole world, with the result, of inestimable value to engineers, that every thread for a given diameter is the same throughout the whole world, for non-Whitworth screws are only used in special cases. It is of interest to observe that the dies for producing the whole series of screws included in his system were originally furnished from Whitworth's works in Manchester. "By his multiform application of the true plane, the slide and the screw, he enabled machines to work with a facility, precision, and cheapness hitherto unknown." But to perfect such work exact manufacturing methods, and suitable testing means in order to check the exactness of manufacture, were required. "I cannot impress too strongly on the Institution," said Whitworth to the Institution of Mechanical Engineers in 1856, "and upon all in any way connected with mechanism, the vast importance of obtaining a true plane as a standard of reference. All excellence of workmanship depends upon it. Next in importance to a true plane is the power of measurement." Hence we see that Whitworth over seventy years ago resolved the problem of fine measurement in relation to engineering industry into two basic elements, the first the production of a true plane, and the second, the absolute reproduction within fine limits of subdivisions or multiples of the imperial yard.

In the early days of the engineer's art, fine measurement in the workshop was an impossibility, and depended entirely on the workman's sense of sight, which not only is an uncertain quality, but distinctly variable, no two persons having in general eyes of the same optical quality. This fundamental

difference in optical quality must inevitably lead to differences in their judgment as to whether or not given points or lines are in true coincidence. Through his intimate personal knowledge of workshop methods and appliances, Whitworth decided that, as a fundamental principle, the most practical and reliable method of dealing with linear measurement as applied to mechanical details was an appeal to the workman's sense of *touch*, as being relatively superior to his sense of *sight*. This is the principle underlying his measuring machine, which may be described in his own words. "The measuring machines which I have constructed are based upon the production of the true plane. Measures of length are obtained either by line or end measurement. The English standard yard is represented by two lines drawn across two gold studs sunk in a bronze bar about 30 inches long, the temperature being about 62° F. There is an insurmountable difficulty in converting line measure to end measure, and therefore it is most desirable for all standards of linear measure to be end measure. Line measure depends on sight aided by magnifying glasses, but the accuracy of end measure is due to the sense of touch, and the delicacy of that sense is indicated by means of a mechanical multiplier. In the case of the workshop measuring machine the divisions on the micrometer wheel represent 10,000ths of an inch. It is found in practice that the measurement of the fourth part of a division, being 40,000th part of an inch, is distinctly *felt* and gauged. In the case of the millionths machine, we introduce a feeler piece between one end of the bar to be measured and one end of the machine, and the movement of the micrometer wheel through one division is sufficient to arrest the action of the gravity or feeler piece."* A similar arresting of the action of the feeler piece takes place after little more than the momentary touch of the finger on the bar to be measured, this constituting a most delicate test of the expansion of a body under the influence of heat.

A survey of the history of measurement in England is not complete until reference has been made to the influence of the metric system, originally the measurement system of France only, but now of many other countries—on the development

* Jeans, *op. cit.*, 225.

of English measures during recent years. The limitation and inconveniences of the English duodecimal system have been realized for a very long period. As early as 1783 James Watt, who at that time was experiencing difficulty in transforming to English equivalents the weights and measures used by the French scientists Lavoisier and Laplace, in some experimental work, wrote in a letter:* "It is therefore a very desirable thing to have these difficulties removed, and to get all philosophers to use pounds divided in the same manner, and I flatter myself that may be accomplished, if you, Dr. Priestley, and a few of the French experimenters will agree to it; for the utility is so evident that any thinking person must immediately be convinced of it. My proposal is briefly this:

"Let the philosophical pound consist of 10 ounces or 10,000 grains.

"Let the philosophical ounce consist of 10 drachms or 1,000 grains.

"Let the philosophical drachm consist of 100 grains.

"Let all elastic fluids be measured by the ounce measure of water, by which the valuation of different cubic inches will be avoided, and the common decimal tables of specific gravities will immediately give the weights of these elastic fluids." He added: "I have some hopes that the foot may be fixed by the pendulum, and a measure of water, and a pound derived from that; but in the interim let us at least assume a proper division which, from the nature of it, must be intelligible as long as decimal arithmetic is used."

In 1798 the French Government convened an International Commission at Paris to examine the work of the French scientists on which the metric system was based, but despite the active solicitations of James Watt, England declined to send a representative or to co-operate with the Commission. In 1789 Sir John Riggs Miller moved in the House of Commons for the appointment of a Committee "to investigate and report on the best means for adopting an uniformity of weights and measures." His plan was supported by the Rev. George Skene Keith, who advocated that in making a change a decimal

* A. Siemens, "Metrical System of Weights and Measures," in *Journal of the Institute of Electrical Engineers* (1903), XXXII. 278.

system should be introduced. Further agitation in Parliament, led, in 1814, by Sir John Wrottesley, resulted in the appointment of a Commission which included Dr. Thomas Young, William H. Wollaston, and Captain Henry Kater, but their report was not favourable towards the decimal system. Despite this decision, the advocates of the decimal system increased in number. A Committee of the House of Commons, reporting in 1862, stated that "it would involve almost as much difficulty to create a special decimal system of our own, as simply to adopt the metric decimal system in common with other nations. And, if we did so create a national system we would, in all likelihood, have to change it again in a few years, as the commerce and intercourse between nations increased, into an international one." The growing interest in the decimal system is marked by the fact that in 1864 the true length of the metre was determined at 39·37079 British inches, a value which was legalized in that year by an Act of Parliament which also permitted the use of the weights and measures of the metric system.

The next important step was taken in 1895, when, in response to demands for further action, a Committee of the House of Commons was appointed to reinvestigate the matter. After examining many witnesses and carefully considering all the evidence, the Committee in their report recommended:

> "(*a*) That the metric system of weights and measures be at once legalized for all purposes.
>
> "(*b*) That after a lapse of two years the metric system be rendered compulsory by Act of Parliament.
>
> "(*c*) That the metric system of weights and measures be taught in all public elementary schools as a necessary and integral part of arithmetic, and that decimals be introduced at an earlier period of the school curriculum than is the case at present."

Acting on these recommendations Parliament legalized metric weights and measures for all purposes on May 27, 1897, but refrained from making the system compulsory. In 1903 it seemed to the members of the Decimal Association, an influential organization which had been formed to further the adoption of the metric system and a decimal system of coinage,

that popular feeling in favour of radical reforms in the system of weights and measures was increasing, and that it was an opportune time to make another legislative attempt. Accordingly, Lords Belhaven and Stenton introduced a Bill, which was supported on its introduction by Lord Kelvin. The third reading of the Bill was passed, and it was sent to the House of Commons, where, however, it was never brought up for passage. The Bill of 1904 provided for the establishment of the standard kilogram and metre from the first day of April, 1909, as the imperial standard of weight and of measure, though for sufficient cause this date could be postponed by an Order in Council. It also provided for Parliamentary copies of the substituted imperial standards, and that future deeds, contracts, etc., must be in terms of the metric system. It further made due provision for various adaptations rendered necessary by the change, and prescribed the general method in which it should be carried out. This Bill was endorsed by a large number of town, city, and county councils, and by over fifty chambers of commerce, including some of the most important in the kingdom; while, in addition to petitions from forty-two trades unions, representing some 300,000 members, the Congress of Trades Unions meeting at Leeds in September, 1904, and representing some 5,000,000 workmen, unanimously resolved to petition the House of Commons in favour of the Bill. There were also petitions from sixty teachers' associations, inspectors of weights and measures in eighty districts, and thirty retail trades' associations, besides numerous chambers of agriculture and farmers' associations. The Bill was supported by eminently practical people as well as scientists and theorists, and it is interesting to observe that in Great Britain retail tradesmen and workmen have been alive to the many merits of the metric system.

Great Britain, however, has taken a prominent part in the development of scientific measures, and the British Association for the Advancement of Science has worked out the present C.G.S.—*i.e.*, Centimetre-Gram-Second—system which is to-day universally adopted by scientists and engineers. During recent years considerable advances have been made in this country towards the introduction of the decimal system of

measurement into the engineering workshops, and although the actual metric standards have not themselves been adopted, the use of decimal divisions of the inch has become quite frequent. The ready applicability of decimal measures in engineering works demonstrates its superiority over the duodecimal system. The common English practice of successively halving the unit introduces such awkward fractions as a 32nd and 64th, and it has become quite common to-day to use hundredths and thousandths of an inch as the standard subdivisions of linear measure in mechanical operations. It is worth while to note that some years ago one large engineering company in England—Messrs. Willans and Robinson, of Rugby—adopted the metric system throughout their works; and one of their engineers in describing the use of the metric system in the shops has written:* "I have seen new machines built in the metric system, side by side with existing lines built in the English system, and I have seen standard parts of one set of machines made to work in with standard parts of the others, and I have also made and sent into the shops drawings in which a single large and complicated casting has been figured in each system. I can make no advance for this latter, but it shows what can be done in working the two systems side by side during the transit period." These works employed bolts whose diameter is turned to the nearest even millimetre larger than the side of the thread, and on them cutting a thread of the standard Whitworth pattern. But it is extremely difficult for isolated works to give complete effect to the metric system, as in dealing with the outside world they must necessarily adopt the imperial standards, and on account of this external difficulty the firm mentioned above have limited the application of the metric system to within their own works.

* Briggs, "The Metric System," in *American Machinist* (1902), XXIV. 450.

CHAPTER III

DOCKS AND HARBOURS

LIGHTHOUSES or beacons and small artificial harbours have been in existence from early times. British vessels at the end of the seventeenth century were of such small burden and so few in number that navigable tidal rivers, such as the Thames, Avon, and Dee, provided all the harbour accommodation necessary for ocean-borne shipping. The various shipping villages scattered round the coast had small stone jetties, such as are to-day found in Devon and Cornwall, situated in naturally protected waters. One of these, Lyme Regis, is described by Macaulay: "The place was then (1685) chiefly remarkable for a pier, which in the days of the Plantagenets had been constructed of stone, unhewn and uncemented. This ancient work, known by the name of the Cob, enclosed the only haven where, in a space of many miles, the fishermen could take refuge from the tempests of the Channel." The same method of construction was adopted for this as for earlier and contemporary jetties or piers. The rocks which formed part of the beach were floated to the proposed site of the pier by means of empty casks and there sunk. Piles made of oak were driven into the sea on either side to hold them in position, and it is noteworthy that in this period timber was considered to be a very important constituent in pier building. A harbour of similar design was built at Hastings, where a pier was constructed of large rocks, without the usual timber supports, but it was completely destroyed by the seas of the following winter. In 1597 another pier was erected at Hastings; much timber was used in its construction, and it was described as "beutyfull to behold, huge, invariable and un-removable in the judgement of all beholders." But on November 1 following its completion a storm completely wrecked this "unremovable" pier, and no further attempt was made to provide Hastings with a stone pier.

During the reign of Henry VIII. Sir John Thompson, Master of the *Maison Dieu*, sought to preserve Dover Harbour. He enclosed, at a cost of £50,000, a small area by means of two rows of piles between which were sunk blocks of stone and chalk, but the sea soon forced its way through, and shingles accumulated until only vessels of 4 feet draught could enter the harbour. The importance of preserving Dover Harbour was early realized, and from time to time the task was taken in hand by both foreign and British engineers, of whom may be mentioned Smeaton, Rennie, Telford, Ferdinand Poins, and Thomas Diggs. It was not until the middle of the nineteenth century, when the Government decided to take an active part in constructing and improving "Harbours of Refuge," that a really satisfactory harbour was made. Bristol on the Avon ranked in the eighteenth century as the second port in the kingdom, having a shipping trade only slightly inferior to that of London. The homeward bound vessels made their way to Bristol on the top of the tide, and lay upon the mud at low water. In order to provide a soft foundation it is recorded that the course of the River Frome was turned in early times to make a "softe and whosey [oozey] harbour for grete shippes." The great strain imposed upon the vessels using Bristol Harbour caused them to bulge and swell out, so that it was said that a practised sailor's eye could readily recognize the Bristol "hog" while still far off at sea. In the middle of the eighteenth century, when Smeaton was consulted concerning many harbour improvements throughout the kingdom, Bristol was one of those which called for his services, but the town, like many others, was unable to find the necessary funds for carrying out his suggestions. It is recorded that the merchants of Bristol gave him a unanimous "vote of thanks" for his report, which was designed to enable vessels at the quay side to remain constantly afloat by means of docks connected with the river. It was not until Liverpool had assumed the premier position among the West of England ports that Bristol interests were aroused and harbour improvements were put in hand under the direction of Jessop, Smeaton's pupil.

The first real progress in harbour building may be said to have commenced with the work of Smeaton, though, for the

most part, new harbour works were confined to the improvement of such primitive harbours as existed. St. Ives, in Cornwall, was naturally protected on the north, west, and south, and only required protection from the east and north-east, which Smeaton provided by the construction of a stone jetty. Following his success here, he was consulted concerning improvements for numerous other harbours: Bristol, as we have just noted, Workington, Whitehaven, Rye, Christchurch, Yarmouth, Dover, Lyne, Scarborough, and Sunderland; but in almost every case the improvements suggested were too costly to be carried out, and the principal harbour works actually constructed were those at Ramsgate. In order to protect large merchantmen from the dangers of the Downs, the need for suitable harbour accommodation in this area had been realized as early as the reign of Queen Elizabeth, the site then suggested being Sandwich; and a Committee of the House of Commons, after taking evidence, reported that "A safe and commodious harbour may be made into the Downs near Sandown Castle, fit for the reception and security of large merchantmen and ships of war, which would also be of great advantage to the naval power of Great Britain." The work was not undertaken, however, as the estimated cost of just under half a million was regarded as excessive. The subject lay in abeyance until 1748, when a great storm drove a large number of ships on to the shore, and only a few were able to make their way to the safety of the small haven at Ramsgate. In consequence an Act was passed in 1749, authorizing the construction of a harbour at Ramsgate, and the trustees of the work accepted a design which was a combination of two of the plans submitted. Operations were commenced at once, but work was suspended in 1755, and nothing further was done for six years. In 1774 Smeaton was called in to advise what steps should be taken, firstly, to remove the enormous accumulation of silt, estimated at 268,700 cubic yards, and, secondly, to complete the harbour works. He accomplished the former by devising a system of sluices supplied by an artificial backwater. His proposed plan of the harbour required the enclosure of two areas of four acres to be provided with nine sluice gates which were to be used at low tide for sweeping away the

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accumulation of silt. These designs were carried out in a slightly modified form, but later the method of sluicing was found to endanger the foundations of the piers. Smeaton was again consulted and, in addition to improvements to the harbour, he was asked to submit designs for a new dock which was commenced in 1784, the floor being paved with timber. The east pier, which had been built of timber, was reconstructed with stone, and was carried out a further 350 feet. In the construction of this pier Smeaton employed the diving bell, which consisted of a square chest composed of both iron and wood, 4 feet 6 inches in height and length, and 3 feet wide, providing room for two men who were supplied with fresh air by a forcing pump situated in a boat floating above them. The harbour when completed had an area of 42 acres, the piers extending 1,310 feet into the sea, with a 200-feet opening between the pier heads. The harbour at Aberdeen was improved by Smeaton in 1770, and he reported on the harbours at Dundee and Dunbar, small improvements being made as a result of his advice. Later he constructed the harbours at Port Patrick and Eyemouth, and he refers to them in his report on Scarborough pier in August, 1781, stating that they had "given entire satisfaction." Rennie reported on Wick harbour in 1793, but, owing to the lack of funds, his improvements were not carried out. The later improvements were made according to designs submitted by Telford, and the work was commenced in 1808, part of the money for which was provided by the town, and the remainder by the Forfeited Estates Fund.

Up to the end of the eighteenth century goods could be loaded and unloaded in London only at certain "legal quays" or under special permit at "sufferance wharves," the numbers of which, and the facilities they offered, being totally inadequate for the rapidly expanding shipping trade even as early as the middle of the eighteenth century. In consequence of this limited accommodation, the cargo of ocean-going vessels was unloaded into lighters and barges in tidal waters, and kept afloat until it could be discharged at one of the "legal quays." Thus the cargo of an Indiaman of 800 tons burden could rarely be discharged in less than a month, and the goods had to be carried by lighters from Blackwall to London Bridge. In these times

the tidal waters of the Thames provided harbour, docks, and depot for all shipping using the port, and this accommodation was so limited as to be almost negligible, for up to the close of the eighteenth century the "legal quays" had only a frontage of 1,400 feet and the "sufferance wharves" of 3,500 feet—the same amount as in 1660. Year by year the congestion became more pronounced, and greater delays were experienced in discharging cargo. The river was further congested when the colliers from Newcastle began to arrive in large numbers. This congestion, coupled with totally inadequate police protection, gave plunderers every opportunity for carrying out their work with impunity, and the annual loss to foreign and coastal trade was estimated to be not less than £500,000. These plunderers went under various names according to the type of vessels and their system of carrying out their work. They were known as River Pirates, Light Horsemen, Game Lightermen, etc., and worked in co-operation with ships' officers and watchmen, with whom they shared their plunder.* As a proof of the enormous extent of this depredation the number of convictions between August, 1772, and August, 1799, exceeded 2,200, and an idea of the profit made is indicated by the fact that of these, 2,000 paid the fines from the funds of a club formed for the purpose. In 1798 the Thames Police were established, but so long as the old method of discharging cargoes was maintained, prevention of pilfering was an unsurmountable difficulty.

The first dock constructed on the Thames was situated on the south bank at Rotherhithe, and had been completed in 1696. This was a dry dock, and had been followed, in 1700, by a wet dock, which was shortly afterwards leased to the South Sea Company and used by them for their whaling ships, under the name of the Greenland Dock. Following this, another private dock, known as Mr. Perry's Dock, had been built, and no further accommodation was provided until the beginning of the nineteenth century. The congestion on the Thames finally reached a point where it threatened to nullify the efforts made to increase the foreign trade of the country, and it was realized that the prosperity of London was dependent upon

* Kirkaldy, *British Shipping*, 472, 479.

increased dock and wharfage facilities and the protection of honest merchants from the depredations of systematic plundering. Rennie was consulted in 1798 and submitted a plan for building, as a result of which it was decided to build floating docks or basins communicating with the river, together with suitable quays and warehouses, to be enclosed entirely by a lofty wall so that both the vessels and their cargoes might be loaded and unloaded in safety and with greater despatch. This plan would at the same time facilitate the collection of Customs duties. The West India Dock Company obtained an Act of Parliament in 1799, and their Charter required that quays, wet docks, and adequate warehouse accommodation should be constructed and protected by a high wall and ditch. The quays were to be "legal quays," and a monopoly was granted providing that all shipping loading for or discharging from the West Indies for the next twenty-one years should make use of this accommodation. The West India Dock, the construction of which was commenced in 1800, and which was partially opened in 1802, and finally completed in 1805, may be said to be the first step in the development of the modern port of London. Other groups of merchants saw possibilities of profit and joined together to obtain similar powers. Plans were submitted to Parliament, with the result that the London Docks were commenced in 1802 and opened in 1805. The East India Docks were completed in 1806, and extensive works known as the Commercial Docks were undertaken on the south bank of the Thames near the old Greenland Dock adjoining the Grand Surrey Canal, between 1811 and 1815.

This rapid extension of dock accommodation during the early part of the nineteenth century was completely adequate for the needs of the period, and no further dock extensions were carried out until 1855, except for the opening of the Regent's Canal in 1820 and the Katharine Docks in 1828. Although the West India Docks may be said to be the direct result of the influence of Rennie, they were designed and constructed by Jessop, whose father had been engaged under Smeaton in the building of the Eddystone Lighthouse, and who on his death left his son in the care of Smeaton, by whom he was adopted as a pupil. Rennie was responsible for the design and con-

struction of the London Docks, and in his usual far-sighted way his plans were so arranged that further extensions could be readily made. The bottom of this dock was laid 20 feet below the level of high water of an 18-foot tide, the entrance lock led into the Wapping Basin, 3 acres in area, and from thence connection was made with the Western Dock, 1,268 feet long and 960 feet wide, covering an area of 20 acres. After these docks were completed, Rennie suggested many improvements in working details. In 1808 he advocated that steam cranes should be employed instead of human or horse labour, but this suggestion was not adopted, although Rennie estimated that it would result in the saving of £1,500 per annum. He also advised the use of tramways to facilitate the carriage of goods from one part of the dock to another, but this suggestion also was received with prejudice and ignorance by those in authority.

The monopolies granted to each Dock Company as it was formed, compelling certain types of shipping to use the proffered accommodation for a period of twenty-one years, proved a hindrance to trade development. A Select Committee of Foreign Trade was set up in 1823 to enquire into their operation, and from its report the following extract may be quoted: "The maintenance and encouragement of the Dock establishment are objects of equal interest to all parties concerned in the commerce of the country; and the principal questions for the consideration of your Committee appear to be whether the advantages resulting from them could be preserved to the public most effectually in a system of exclusive privilege, granted to each dock respectively, by which the trade should be by law divided and apportioned; or one of competition operating freely amongst them, in which the convenience of commerce, whether arising from local position, regulation, or charges, should be alone the measure of employment and advantages enjoyed by each several establishment." The main points to be considered were "those only which are connected with the security and facility of collection of the revenue, and protection of the property of the merchant, unseparable from it, and how far these advantages are dependent in general, or in the case of the West India trade, in

particular, upon the continuance of the system of exclusive privilege." After acknowledging the general principle that open competition would be of great advantage to the public, the report proceeds: "It was necessary to hold out liberal compensation to those who had invested their capital in a speculation which, whatever advantages it might eventually promise to the Adventurers and the Public, was in its commencement of doubtful success"; and, again: "In the present case, the claims that arise from the hazard of doubtful experiment which originally recommended the grant of exclusive privileges have long since vanished. The success of the experiment is decisively ascertained—the investment of capital has been fully compensated—and the advantages of docks are universally acknowledged." As a consequence, future charters for the construction of docks did not incorporate these same privileges. The beneficial effect produced by the dock and warehouse accommodation in affording protection from theft may be gauged from the evidence of Thomas Groves, Inspector-General of Imports in the Port of London, who stated in evidence before the Select Committee mentioned above that "he had occasion to enquire about Christmas last the extent of the pilferage (all gates being guarded by police officers, excise officers, and officers of the custom, who are all jealous of each other, and watched as closely as possible), and that the value of all seizures made at the gates in twelve months amounted only to forty shillings."

While Rennie, during the first years of the nineteenth century, had been principally engaged on the construction of the London docks, he had also been consulted over many other projects, notably by the Admiralty over the protection of the harbour of Plymouth. In April, 1806, he presented his report, in which he suggested a design which entailed less expense than the plans previously submitted, and had the further advantage of guarding against the accumulation of silt. His plan was to construct a breakwater across the middle of the Sound, occupying a portion which was rarely used for navigation owing to the presence of rocks. He proposed to throw into the sea rubble of large size, each block to be from 2 to 12 tons in weight, leave them to find their own level, and so form

a ridge 70 yards wide at the base and 10 yards wide at the top with a total length of 5,100 feet. Each end of the breakwater was to be inclined landwards at an angle, and the total cost was estimated at £1,102,440. Rennie had previously constructed small breakwaters on a similar plan at Kingstown and Holyhead, so that the idea was not new, but nothing had ever been attempted on so large a scale. The scheme was subjected to much criticism, and it was not until 1811 that the plans were finally passed by the Admiralty. A piece of land, 25 acres in area, was bought from the Duke of Bedford at Creston, where limestone could be easily quarried and carried by boat to the site of the breakwater. For two years material was deposited, until in March, 1813, at low water, portions of the work were visible, and by March, 1814, the effect of the breakwater was felt, and the waters of the Sound were kept comparatively tranquil during violent storms from the south. By August, 1815, 615,057 tons of stone had been deposited, and 1,100 yards of the work lay exposed at low spring tides. Eventually after much discussion and the failure of the work to maintain a slope of three in one as designed, a slope of five in one was adopted, and stone was laid at the rate of 1,030 tons per day during 1816. The work was not finished until 1848, when 3,670,444 tons of stone had been deposited together with 22,149 cubic yards of masonry laid at a cost of one and a half million pounds.

One of the most remarkable examples of the transformation of a small port, with few natural advantages, into one of worldwide importance and provided with many miles of commodious docks, is afforded by the port of Liverpool. It was not until the eighteenth century that Liverpool absorbed the Irish traffic, as prior to this date communication with Ireland was maintained by the port of Chester on the Dee. It is interesting to record the figures for the levy on the ports, made by Charles I., which give a clear indication of the relative importance of Liverpool as compared with the other ports:

London	25 ships	662 men.
Bristol	24 ,,	660 ,,
Hull	16 ,,	466 ,,
Portsmouth	5 ,,	96 ,,
Liverpool	1 bark	6 ,,

In 1650 there were about fifteen vessels of 15 to 20 tons burden which belonged to the port, and which were used in the Irish and coasting trade. Towards the end of the seventeenth century the Liverpool merchants took the first step towards the development of accommodation for shipping, and enlisted the assistance of a qualified engineer, Thomas Steers, who suggested that the "Pool" should be enclosed and converted into a wet dock with a gate to retain water at all states of the tide. The Corporation accepted the scheme, which was approved by Parliament, and in 1715 the dock was opened. This dock was filled up in 1821, and the site is now occupied by the Old Customs House. The merchants of Liverpool realized that the future prosperity of the port depended on suitable dock accommodation, and developed its resources to a greater extent than any other port. Shortly after the completion of the first dock at Liverpool, in 1717, powers were obtained to build a dry dock, and the increase in the shipping trade of the port may be gauged from the record that in 1752 Liverpool possessed 256 vessels. The volume of the trade of the port increased so rapidly that in 1771 the George's Dock was opened, and was followed rapidly by the King's Dock in 1785 and the Queen's Dock in 1789. In 1799 parliamentary powers were obtained to enlarge George's Dock and also to construct another dock to the north of it, the Clarence Dock, which was completed in 1830. The area of dock accommodation had reached 34 acres in 1816, and in spite of this development Rennie wrote to a correspondent at Liverpool in 1810: "It seems to me that your merchants are much less liberal in their ideas than is generally supposed. The account you give me furnishes another strong proof of the necessity of enlarging your scale of docks."

Ports may be divided, from the point of view of dock construction, into two main groups. Where the rise and fall of the tide is considerable, as at Bristol and Liverpool, it is necessary to have a system of closed docks—that is, each ship must enter or leave by the process of "locking"—and especially this is so where vessels can only reach the port during high tide. Where the difference in level between high and low tide is comparatively small, as at Glasgow, a system of open locks or basins is made possible, and—provided that the river is suffi-

ciently deep to permit the largest vessels to approach at all states of the tide—such a system is a great advantage. It obviates the necessity for dock gates, and permits the use of riverside wharves where the waters of the harbour are sufficiently tranquil to permit vessels to berth in the river itself. This is especially an advantage in a port such as London; here the bulk of the cargo is transhipped to barges and carried up-river where vessels of deep draft cannot make their way, and thence reach their destination through a system of canals. The estuary of the Mersey is not sufficiently protected to permit of the use of barges, as in the case of the Thames, and in consequence all shipping discharges its cargo into warehouses or transhipment sheds, and from thence it is conveyed to its inland destination by rail.

The accumulation of silt presents a great difficulty at Liverpool, and in order to keep the channels and docks clear an elaborate system of dredging has been instituted. The Mersey Bar, a bank of sand and silt, situated about 13 miles from the Liverpool Docks, has been a serious handicap to the port of Liverpool, being a constant source of danger to vessels and barring the approach to the port at low water. The limitation imposed on the size of vessels using the port, and the number of hours per day at which the state of the tide permitted vessels to enter the port, made the removal of the Bar obstruction one of the main objects of the improvements contemplated towards the end of the nineteenth century. In 1890 two small hopper dredgers, each of 500 tons capacity, were adapted for the work of lowering the Bar and fitted with centrifugal sand pumps. A favourable report being made on the results of their work in 1893, a new vessel, the *Brancher*, of 3,000 tons capacity, was brought into use. This vessel was followed by the *G. B. Crow*, which commenced work in 1895. The work progressed so favourably that two further vessels were added to the dredging fleet—the *Coronation* and the *Leviathan*—at a cost of £75,000 and £150,000 respectively. This latter vessel has a capacity of 180,000 cubic feet, and can fill itself in fifty minutes, drawing from a maximum depth of 70 feet. Before dredging was commenced the depth of water at the Bar at low spring tide was 11 feet, while in 1914 this had been increased

to about 35 feet. The space over which the dredging has been carried out at the Bar covers an area of 6,000 feet by 1,500 feet, the latter figure being the average width of the buoyed channel across the Bar. It is now possible for almost any vessel afloat to come over the Bar at any state of the tide, and proceed through the Queen's and Crosby Channels into the Mersey, and, if necessary, go alongside the landing stage and disembark the passengers.

The most recent development at Liverpool is a scheme for the construction of a series of new docks on the north bank of the river, in which the largest liners afloat would find accommodation. Parliamentary powers were obtained in 1906, but owing to the depressed state of the shipping industry a start was not made until 1910, when it was decided to construct the Gladstone Dock—so called after Robert Gladstone, a former Chairman of the Mersey Dock and Harbour Board. "It was also decided that the Dock should be so constructed as to be available for use as a graving dock by the largest vessels afloat. This dock was duly completed and formally opened by His Majesty King George V. on the 11th July, 1913. The dock is 1,050 feet long and 120 feet wide at the entrance. On the north quay of the dock there is a single storey shed 900 feet long and 100 feet wide in two spans, and provided on the dock front with four 30-cwt. movable cargo cranes electrically operated. The dock is closed by means of a caisson which is drawn across the entrance. When not required in position across the entrance, the caisson is withdrawn into a recess in the south side. When the dock is required for use as a graving dock it is rapidly cleared of water by five centrifugal pumps having discharge pipes 54 inches in diameter, each pump being driven direct by a Diesel engine. The whole installation is capable of emptying the dock of its contents, amounting to about 44,000,000 gallons, or, say, 204,000 tons, in 2½ hours."*

Liverpool gradually evolved a "Port Authority" through the medium of which new works were constructed in conformity with a definite plan. In 1761 all matters concerning docks, piers, buoys, and allied works were vested in the mayor,

* *The Port of Liverpool*, Special Civic Publication (1914), 42.

aldermen, bailiffs, and common councilmen of Liverpool, who were empowered to bring and defend actions in the name of the Trustees of the Docks and Harbour of Liverpool. In 1811 this Authority was delegated to twenty-one members of the Common Council, known as the Trustees of the Liverpool Docks, a corporate body with a Common Seal, subject to the veto of the Common Council. In the year 1825 the dock ratepayers were first represented and eight of the twenty-one members were elected by the ratepayers, and in 1851 the numbers were changed, twelve nominated by the Common Council and twelve by the ratepayers, and the elected body was then known as "The Committee for the Affairs of the Estate of the Trustees of the Liverpool Dock." A Royal Commission was appointed in 1853 to consider the needs of the port, and as a result, in 1858, the "Mersey Docks and Harbour Board" was constituted by Act of Parliament to take control of all matters relating to the port. During recent years the value sterling of the exports and imports of Liverpool has exceeded those of London for the first time, and thus this port has taken pride of place as the first port of the kingdom. While the total value for London in 1920 reached approximately £750,000,000, the corresponding figure for Liverpool exceeded £1,100,000,000. Such has been the result of the careful and organized design of the Liverpool Docks.

Glasgow has similarly grown to its present size owing to the impetus to trade for which its shipping development has been responsible. At the beginning of the eighteenth century Glasgow had practically no shipping, although in the middle of the seventeenth century it possessed twelve vessels, of which four were the largest in Scotland at that time, three being of 150 tons and one of 140 tons burden. The trade of the town was then largely devoted to the manufacture of woollen goods, linen, clothes, soap, sugar, leather, spirits, rope, and paper; and its foreign trade was almost negligible, due in part to the excessive shallowness of the river and the inaccessibility of the town itself to large vessels. But that the merchants were not altogether lacking in enterprise is shown by the fact that they took the first steps towards deepening the river in 1760 at a cost of £100. It was not until 1806 that real progress

was made in the deepening of the channel and the "training" of the river into the desired course. The improvements then made enabled a vessel of 120 tons and drawing 8 feet of water to sail as far as Glasgow itself,* and since then the river has been deepened from between 28 to 33 feet below the original level and 23 feet below the level of low water. In order to carry out this enormous work, islands have had to be removed and channels filled in, and a rib of rock at Elderslie, which blocked the passage, had to be blasted and removed, an item which alone cost £150,000. As already stated, Glasgow is a port of open docks which can be entered or left at all states of the tide, and in addition the wharves in the basins and banks of the river are also valuable for the berthing of ships. In 1850 the wharfage accommodation had a length of 2 miles, and this has since increased to more than 12 miles in recent years.

The development of the port of Hull (correctly named Kingston-upon-Hull) has synchronized with the increasing draft of ocean-going vessels. Formerly foreign vessels using the estuary of the Humber made their way to Beverley and Hedon, but towards the middle of the eighteenth century when the whale-fishing increased, parliamentary powers were obtained giving permission to the "Dock Company of Kingston-upon-Hull" to build a dock, the construction of which was commenced in 1775. The development of the port of Hull has been carried out by the railway companies, and its proximity to the great coalfields of Yorkshire, Derbyshire, and Nottinghamshire has made it an important coaling port. As the necessity for increased dock accommodation on the Humber was realized parliamentary powers were obtained in 1901 and 1904 authorizing the construction of a new dock at Immingham. The work was commenced on July 12, 1906, and the dock opened on July 22, 1912. The port of Immingham is situated midway between Hull and Grimsby, and is specially designed for dealing with the export of coal from the South Yorkshire, Nottinghamshire, and Derbyshire coalfields, and for the import of iron ore from Spain, Norway, and Sweden. An important feature of the dock is its accessibility, vessels being able to berth at any

* Kirkaldy, *British Shipping*, 539.

state of the tide, day or night. The dock has eight coal hoists, each of which is capable of shipping 700 tons of coal per hour, and the sidings have a storage capacity for 170,000 tons of coal.

One of the most noteworthy of modern harbours constructed to meet the ever-growing demand for quick transport is Fishguard, which enables transatlantic passengers to travel by the Great Western Railway from London and catch the west-bound liners after they have left Liverpool, or *vice versa*, thus saving many hours between London and New York. In recent years the fast transatlantic passenger traffic has moved to Southampton, and consequently the importance of Fishguard has been diminished. The harbour is situated on the northern coast of Pembrokeshire in the south-west extremity of Wales, and is historically famous as being the scene of the last invasion of Britain—by a small French force in 1797, which was speedily evicted by the Welsh Militia. The possibilities of this situation for a harbour were recognized at the end of the eighteenth century, when the Admiralty considered the construction of a harbour there, but nothing was done and the project dropped until 1845, when a railway was planned to serve South Wales. The railway plans being altered, there was no result, and it was not until 1893, when the Fishguard Bay Railway obtained parliamentary powers to run a service of steamers to Rosslare, on the Irish coast, that interest was aroused. The capital for this undertaking was found by the Great Western Railway and the Great Southern and Western Railway of Ireland, and the construction was taken in hand of a harbour which would serve the Irish trade and be a port of call for the Liverpool-America liners, in connection with which the Great Western Railway ran a boat train service from Paddington. The undertaking entailed the removal of the cliffs, which in places rose to a height of 300 feet, to make way for the railway, station, sidings, and wharfage accommodation. The material dislodged by blasting was used for the construction of the breakwater, which ran out to sea for a distance of 2,000 feet. This work required the removal of some 2,000,000 tons of rock, as much as 100,000 tons being dislodged at one blast; these operations lasted for four years, and an area of 27 acres was

made available for railway purposes. The breakwater is 300 feet wide at the base and 70 feet at the top, and has a height from the sea-bed of 70 feet. The wall of the quay was built of concrete blocks, each weighing from 6 to 11 tons, which were carried and lowered into position by a "Titan" crane on to the bare rock of the sea-bed, the latter having been exposed by the removal of the shingle by means of a grab hopper barge, and the inequalities made level by divers using concrete in bags. Upon this foundation the blocks were lowered and placed in position, and the wall was raised to within 3 feet of high water. Above this level "mass concrete" shaped in casings or moulds completed the wall above water. On the face of this wall a gallery extends for the whole length of the quay under the passenger and cargo space, and enables cattle to be disembarked from any gangway of a vessel; and subways are provided which permit access to the cattle pens at the rear of the station.

The construction of special graving docks has been occasioned by the increase in tonnage of modern vessels to the extent that they cannot safely be allowed to rest unsupported on the soft floor of an ordinary dock, or on the bank of a river or estuary, without danger of straining their timbers or plates. In addition, Lloyd's Register now demands that ships docked for repairs, painting, and cleaning must be placed on an even keel in a "graving,"* or, as it is more frequently styled, a "dry dock." Such a dock is usually a long and narrow basin, sometimes capable of being divided into two portions. After the ship has entered through the dock gates the water is pumped out and the ship is allowed to settle on to a bed specially prepared to receive the keel, and at the same time props or struts are inserted between the ship's sides and the walls of the dock, which are built on the slope in a series of steps. In this way the weight of the ship is carried mainly on the keel

* The name "graving" dock owes its derivation to early usage. In early ages vessels at the conclusion of long voyages were beached and the accumulated seaweed and marine grass, etc., removed from the hull by burning or breaming. After this process the vessel was "graved"—*i.e.*, smeared over with tallow. "Graves" or "greaves" was the old name for the sediment or lowest quality of melted fat, which preceded the use of pitch or tar, which has now, in the days of steel and iron ships, given way to anti-corrosive paint.

blocks, and the sides of the vessel are protected from bulging by means of these props or "shores," which, incidentally, provide the scaffolding for the ship repairers and painters. This is the method adopted for land graving docks, but with the growth of the mercantile marine it has been found desirable to provide harbours with what are known as floating docks, which, in effect, are **U**-shaped vessels with two parallel vertical sides, connected below water by a hull and the ends fitted with gates similar to the usual dock gates. A vessel requiring attention is towed between the walls of the "dock," and when the vessel is fixed in position the gates are closed, the water pumped out, when the whole structure rises in the water and the vessel enclosed is completely out of the water. A notable example of a floating dock was the *Bermuda*, which was launched in 1902 and towed across the Atlantic to Bermuda Harbour. It has an overall length of 545 feet, and can take a vessel of 32 feet draft.

Beacons and towers on prominent headlands were used for guiding vessels from very ancient times. After the Romans left England the lighthouses they had constructed fell into decay and no new ones were built, as the need for guiding vessels across the English Channel no longer existed. When, later, the piratical Northmen descended upon the shores of Britain, the inhabitants erected fire beacons on the coast to give warning to the people inland. In the time of Henry III. every ship using the port of Winchester—now several miles inland—was subjected to a levy of 2d. for the maintenance of the light provided for the safety of vessels entering by night. In the time of Edward III. lights are said to have been shown along the coast, but these were merely bonfires, except in Kent, where it was ordered that "pitchpots" should be built on high standards. These early beacons served the dual purpose of guidance for those sailing the seas during the night and as a warning in case of foreign invasion. Later, coal replaced wood, and remained in use for this purpose until as late as 1822.* The coal fires, when stirred, emitted a bright light

* On this date coal is last recorded as being used at St. Bees. Smiles, *Life of Smeaton and Rennie* (ed. 1901), 41.

which gradually died down until again stirred up by the light-keepers. Such fluctuating light was obviously unsatisfactory.

The first attempts to place the lighting of our coasts on an organized basis were undertaken by Henry VIII., who founded Trinity House in 1515. It was styled "The Brethren of the Most Glorious and Undividable Trinity," and—typical of the times—prayed for the mariners at sea, but did not erect lighthouses. It was a monastic institution rather than a body of lighthouse keepers. Its duties for a long time were confined to the Thames, and the only part it took in the lighting of the coast was by the granting of leases from the Crown for a specific period of years to those who were willing to find the means of erecting and maintaining beacons, in return for which they were authorized to collect tolls from passing shipping. The ostensible object of erecting lighthouses was to save life, but in practice it became merely a commercial proposition, and though instrumental in saving the lives of many seamen, the lights were also a very profitable source of income, the extent of which may be judged when it is known that when the Trinity Board took charge of the lighthouse on the Skerries Islands off Holyhead they were compelled to pay the owner £450,000 in compensation. The introduction of these guiding lights put into the hands of those who cannot be described as less than barbarians the means of reaping a rich harvest from the wreckage of vessels lost on the coast, lured to destruction on dangerous parts of the coast by means of false lights. The attitude of many of these individuals may be gauged from Kingsley's account: "Wild Folk are these here, gatherers of shell fish and laver, and merciless to wrecked vessels, which they consider their own by immemorial usage or rather right divine. Significant how an agricultural people is generally as cruel to wrecked seamen as a fishing one is merciful. I could tell you twenty stories of the baysmen, down there by the Westward, risking themselves like very heroes to save strangers' lives and beating off the labouring folk who swarm down for plunder from the inland hills."*

During the early part of the eighteenth century a large number of vessels from the West and East Indies, carrying

* Kingsley, *Prose Idylls*, 261.

valuable cargoes, were wrecked on rocks and promontories on the sea-coast, and it was realized that some provision must be made to safeguard both human life and ships. Following the first Eddystone structure, which was washed away within three years of its completion in 1700, the Brethren of the Trinity obtained an Act of Parliament authorizing them to rebuild the lighthouse and to lease out the work. This was undertaken by Captain Lovet, who employed Rudyard, whose design offered the maximum resistance to wind and waves. The outline adopted was that of a cone, and the main defect was the use of wood for its construction. Dovetailed holes were bored into the rock into which iron bolts were keyed and the interstices filled with molten pewter; a base of solid wood was raised above this, firmly fitted and tied together, and to give additional vertical pressure and greater resistance numerous courses of Cornish moor stone were introduced and clamped with iron. The lowest room was situated 27 feet above the highest side of the rock, the upper part of the building consisting of four rooms, one above the other. The lantern lit by candles was fixed upon the roof and was raised 70 feet above the highest point of the foundation. The structure was completed in 1709, though the light was first shown as early as July 28, 1706, concerning which the following anecdote is worthy of record: "As at that time there was war between France and England, a French privateer seized the opportunity of carrying off the men employed upon the rock and taking them as prisoners to France. The news of this reached the ears of Louis XIV., who immediately ordered that the prisoners should be released and taken back to their work with presents, declaring that 'though he was at war with England, he was not at war with mankind, and that, moreover, the Eddystone Lighthouse was so situated as to be of equal service to all nations having occasion to navigate the channel that divided France from England.'"* This lighthouse served until December, 1755, when the lantern caught fire and rapidly enveloped the wooden fabric in flames. The light-keepers were forced to take shelter under a ledge of rock, and were taken off by some fishermen who went to their rescue. Following

* Smeaton, *Narrative of Eddystone Lighthouse*, 28.

the demolition of this structure, steps were taken to erect another lighthouse in its place. Smeaton's association with the Eddystone Lighthouse commenced at this point, when, on the recommendation of Lord Macclesfield, he was invited to prepare a design for a new lighthouse.

John Smeaton, the son of an attorney, was born at Austhorpe Lodge, near Leeds, on June 8, 1724. He received his early education at home, and employed his leisure time in making models of houses, pumps, and windmills, and watching any carpenters or masons who happened to be at work in the vicinity. He then proceeded to Leeds Grammar School. He left school at the age of sixteen and helped in his father's office copying legal documents, but took no pleasure in his work, and spent all his spare time in his workshop. To turn him from this distraction his father sent him to London to study law in 1742, but he found his work intensely irksome, though in spite of this he assiduously applied himself to his studies. After a short period he wrote to his father for permission to follow his natural inclinations, and, upon receiving his consent, entered the service of a scientific instrument maker. He sought out educated men and attended meetings of the Royal Society, and in 1750 read a paper on "Improvements in the Mariner's Compass." In 1754, in the course of a visit to Holland, he inspected the engineering works of all the districts through which he passed, and gained experience that proved of inestimable value when later he turned his attention to the construction of canals, bridges, and harbours.

Robert Weston with two others had purchased the Eddystone Lighthouse from Captain Roberts, and upon deciding to rebuild in 1755, Mr. Weston applied to the Earl of Macclesfield, President of the Royal Society, asking his advice as to whom he should entrust with the new work. Lord Macclesfield strongly recommended Smeaton, to whom Weston immediately wrote, but owing to a misunderstanding Smeaton gathered from the letter that only repair work was wanted, and in consequence replied that he had many engagements and could not leave upon an uncertainty. He received a second letter informing him that the lighthouse was a total wreck, and concluding with the words: "Thou art the man to do it."

Smeaton undertook the work, and definitely decided that the material for the construction of the new lighthouse must be stone, and this in spite of strong counsels that timber would be superior; in addition, he was convinced that the great fault in the previous building had been its lack of weight, and that it would probably have been washed away in a storm sooner or later had it not met disaster by fire—a danger to which any wooden lighthouse would always be exposed. Briefly, his method of construction was as follows: He decided that the outline should correspond with the trunk and bole of a large oak-tree—that is, a column with an exceedingly large base, which rapidly tapered for some distance, then took on a more or less cylindrical form. For ensuring the secure binding of the stone blocks used he adopted a process of dovetailing which, although known in carpentry, had never been applied to masonry, so that the blocks mutually locked themselves together, the first course being secured to the rock itself, and the subsequent courses up to the floor of the first room all proceeding from and being locked to one large centre stone. Smeaton then set out, in March, 1756, to make his first inspection of the rock, and at Plymouth met Josias Jessop, who was a foreman of shipwrights at Plymouth Dock and whose son* later became Smeaton's pupil. After five vain attempts to land on the rock, he was able, on April 22, to make an inspection, and again visited the rock the following day. During these two visits he was able to spend some fifteen hours on the rock, and later paid further visits for the purpose of correcting his measurements and providing for an improved landing-place. On his return to London he proceeded to make a complete model of the lighthouse as he intended it to be built, and he explains why he undertook the construction of the model with his own hands: "Those who are not in the practice of handling mechanical tools themselves, but are under the necessity of applying to the manual operations of others, will undoubtedly conclude that I would have saved much time by employing the hands of others in this matter. But such as are in the use of handling tools for the purpose of

* He was responsible for the design and construction of the West India Dock. *Supra*, 36.

contrivance and invention, will clearly see that provided I could work with as much facility and dispatch as those I might happen to meet and employ, I should save all the time and difficulty, and often the vexation, mistakes and disappointments that arise from a communication of one's own ideas to others; and that when steps of invention are to follow one another in succession and dependence on what preceded under such circumstances, it is not eligible to make use of the hands of others."* Each new course required fresh adaptations and new forms to give the necessary firmness and stability to the work, and after two months' careful work the model was completed and submitted to the proprietors of the lease and unanimously accepted; the Lords of the Admiralty were also satisfied. Smeaton then arranged for a supply of Portland stone, and appointed Jessop general assistant. Work was commenced on August 3, 1756, and was carried forward with many interruptions due to heavy seas and bad weather. Even when the weather was favourable only six hours' work could be done at a time, and in order to expedite progress work was carried on by torch light when necessary. The first season was devoted to the preparation of the dovetailed recesses on the rock foundation, and to save time in proceeding between the rock and the shore a store vessel called the *Neptune* was anchored adjacent to the rock. By the end of November the requisite preliminary work on the rock had been accomplished, and the winter was spent ashore in preparation for the commencement of building operations. On the morning of June 12 of the following year the first stone, weighing $2\frac{1}{4}$ tons, was landed and secured. The work continued as the weather permitted during the summer, the stones being arranged in their courses on shore and then brought to the Eddystone in correct sequence and fixed in their proper places. In this way no confusion occurred on the rock, and by June 30 six complete courses had been laid, and at this stage the work was found to be above the average wash of the sea, which enabled progress to be made much more rapidly. To give additional firmness oak wedges and cement were inserted in grooves cut from top to bottom in each block, and by this means perfect rigidity

* Quoted by Smiles, *Lives of the Engineers*, "Smeaton" (ed. 1904), 138.

was ensured. At various times heavy seas caused damage by washing away stones, tools, and materials, but these losses were quickly made good, and by the end of the year the ninth course was complete. In 1758 work was resumed on May 12, and an examination of the preceding year's work showed that the cement had set as hard as the stone itself, and that no damage had been done by the winter seas. By a great effort Smeaton was able to complete the solid foundation and the lower store-room, with the object of erecting a temporary light for use during the ensuing winter, and arrangements were made to carry this into effect. The Corporation of Trinity House, however, refused permission, and instead of providing a beacon of safety, he was compelled merely to erect a temporary house over the work to give it protection during the winter. The lantern was glazed and the light first exhibited on October 16, 1759.

During the latter half of the nineteenth century much work was carried out in providing adequate lighthouse protection. Among the important undertakings which may be mentioned are the following: the Dhu Heartach Lighthouse, built in 1867-73; the Wolf Rock Tower, built on a foundation below the level of high water; and the New Eddystone Lighthouse, which was built in 1878-82, which has a height of 122½ feet above high-water level as compared with the 60 feet of Smeaton's lighthouse. A lesser known lighthouse, the Bishop Rock, was commenced in 1847 of skeleton iron-work frames, planned by Douglass, the superintending engineer of Trinity House, who considered that this form would offer the greatest possible resistance to the waves, and would be the most suitable type for this isolated rock. During the winter (after work had been suspended in the autumn of 1849) a great storm arose which washed the rock completely bare except for a few short fragments of the main columns, and Douglass then prepared a design, using granite as his material, dovetailed after the manner employed by Smeaton in his Eddystone and Bell Rock lighthouses. In the construction of this new lighthouse, which was commenced in 1851, the lowest stone was laid at a depth of 17 feet below high-water level, and the difficulties experienced were so great that the foundation-stone itself could

not be laid until some three years after the work had been in progress; in 1858 the lighthouse was completely finished and brought into service. Such was the violence of the waves in heavy storms that prisms of the lighting apparatus and some of the blocks of granite were split by the vibration, and in 1881 Douglass was again called upon to assist in the work of protecting and improving the Bishop Rock Lighthouse, which now stands to-day perfectly solid and safe. The principles of lighthouse construction which Smeaton employed in the building of the third Eddystone Lighthouse have been employed in all subsequent lighthouse works up to the present time. The security which they afford to all shipping has encouraged the building of larger and still larger vessels, which have not only increased the economical carrying of cargo and the comfort and security of the passenger traffic, but have again made necessary the improvements to the harbours and the installation of the great dock works for their reception.

CHAPTER IV

CANALS

DURING the past century roads and railways have been of primary importance in facilitating internal transport, and canals have occupied only a secondary position. But in the opening years of the nineteenth century the situation was different; the roads of the country were bad in the extreme, and railways had not been constructed. Canals provided the only means of easy transport. It was under these circumstances that Richard Cobden declared that our canals were regarded by foreign observers " as the primary material agents of the wealth of Great Britain."

Before tracing the story of canal engineering the effort of those who, in earlier times, either combated or used the power of water calls for mention. Down to the end of the sixteenth century the country lying between the Wash and the Thames, known as the Fens, was a great swamp—a sea in winter and a dry waste in summer. From earliest times spasmodic attempts had been made to reclaim parts of this land from the sea, and in places success appeared to crown the efforts that were put forward; but such success was temporary, and when a particularly heavy sea swept the East Anglian coast, it carried all before it, and razed to the ground the little settlements that had been established on the reclaimed portions. The first Act of Parliament providing for the reclamation of the Fens was passed in the reign of Elizabeth, and " gave a legal basis to the action of adventurers in different parts of the Kingdom and rendered it possible to undertake works on the necessary scale."* In 1607, during the reign of James I., some very violent floods swept across the east coast, causing extensive damage and much loss of life. The King, on hearing of the disaster, is reported to have declared that " for the honour of

* Cunningham, *Growth of English Industry*, "Modern Times," I. 114.

his kingdom, he would not any longer suffer these countries to be abandoned to the will of the waters, nor to let them lie waste or unprofitable; and that if no one else would undertake their drainage, he himself would become their undertaker."* It is interesting to observe that the term "engineer" had not then come into use, the word "undertaker" being used to describe the person skilled in the carrying out of what we now call "engineering works." As a consequence of the royal interest in the problem of the drainage of the Fens, a corporation was formed to continue the attempt which had been commenced under Elizabeth. At this period English engineering was very backward, and foreign skill had to be requisitioned for every difficult engineering task.

Reports of the skill of the Dutch engineer Cornelius Vermuyden had reached this country, and he was invited about the year 1621 to undertake the drainage of the Fens. Vermuyden did some good work; he repaired a breach in the Thames at Dagenham, in Essex, and reclaimed a considerable portion of land in Lincolnshire, and developed schemes for the reclamation of the Norfolk and Cambridge Fens. He received many tokens of royal favour from both James I. and Charles I., but he was not without his enemies. Among the latter were the English populace, who resented the intrusion of the foreigner and the increasing number of workmen who from time to time were brought from Holland to East Anglia to assist in carrying out his schemes. On more than one occasion mobs of Fenmen cut the embankments and blocked the drains, with the result that the land was again flooded. In 1642 Vermuyden wrote a "discourse" on the drainage of the Fens, in which he advanced many bold schemes for the improvement of that territory. He seems later to have become involved in financial difficulties, and last appears in public life in 1658, when he appealed, apparently without success, to Parliament for assistance.

In 1707 the sea broke through again at Dagenham on the Thames, and for a time it appeared as though the Dagenham breach was to defy the engineering skill of the country, but in 1715 Captain John Perry undertook the work. Perry was

* Quoted by Smiles, *Lives of the Engineers*, "Brindley" (ed. 1904), 18.

a native of Gloucestershire, and spent the early part of his life at sea, where he displayed great mechanical skill and ability. In 1698 he was brought to the notice of the Czar Peter, then in England, and was invited to proceed to Russia to engage in engineering work. In 1712, after varying fortunes in Russia, he returned to England. On his return he heard of the difficulty that was being experienced in breaching the gap of the Thames, and became interested in the problem, and resolved to try and find a solution. He contracted to execute the work for £25,000, and his offer being accepted, he commenced early in 1715. He stopped the breach by first driving in a row of timber piles dovetailed into one another, and surrounded this by a dam fitted with chalk, on the outside of which a wall of chalk rubble was made as a security, and gradually an embankment was built to hold in the river along the whole of its course at Dagenham. About 300 men were employed in stopping the breach, which took about five years to accomplish.

An equally urgent task, which required engineering skill for its solution, was the supplying of water to meet the requirements of the population of London. During the sixteenth century the water-supply of the Metropolis was inadequate, and every precaution was taken to safeguard the water that was brought to the city through conduits, which supplemented the supply from the wells within the city. Anyone who interfered with the flow of water through the sixteen public conduits was dealt with most severely. We find a curious instance of this in the City Records, from which it appears that on November 12, 1478, one William Campion, resident in Fleet Street, had cunningly tapped the conduit where it passed his door, and conveyed the water into a well in his own house, "thereby occasioning a lack of water to the inhabitants." Campion was immediately taken before the Lord Mayor and aldermen, and after being confined for a time in the Comptour in Bread Street, a further punishment was inflicted on him. "He was set upon a horse with a vessel like unto a conduit placed upon his head, which being filled with water running out of small pipes from the same vessel, he was taken round all the conduits of the city, and the Lord Mayor's proclamation of his offence and the reason for his punishment was then read.

When the conduit had run itself empty over the culprit, it was filled again." As the population of the city grew, the need for additional engineering works to facilitate an adequate water-supply increased. Valuable assistance in this work was given by Hugh Myddleton, a London goldsmith and Recorder of Denbigh, who was elected in 1603 to represent that borough in Parliament. The subject of the water-supply of the northern part of the City of London had been frequently discussed by Parliamentary Committees, of many of which Myddleton was a member. Finally an Act was passed empowering the construction of a works designed to effect the supply, but difficulty was experienced in discovering a suitable man to undertake the work. In the absence of anyone who would undertake the duty, Myddleton volunteered to bring water from Hertfordshire to London. On March 28, 1609, the Corporation formally accepted his offer to bring a water-supply to Islington as being a "thing of great consequence worthy of acceptation for the good of the city." No sooner had Myddleton commenced the works than considerable opposition was raised, particularly by the owners and occupiers of land through which the proposed new river was to pass. So virulent had the attacks of his opponents become that he finally appealed to the King, James I., who came to his assistance and enabled him to complete the enterprise. Finally, on Michaelmas Day, 1613, the public of London held a pageant to celebrate the entry of the New River water into the Metropolis, the actual ceremony being attended by the Lord Mayor and aldermen of the city. The original water-pipes were made of wood, principally elm, and at one time as much as 400 miles of this piping was laid through the streets of London. Through continual leakage these were very unsatisfactory, and were later replaced by cast iron pipes. The New River enterprise was characterized more by the colossal nature of the undertaking than by any special engineering features, being the largest piece of work of its kind hitherto attempted in England.

Evidence of the growing interest in internal water transport is afforded by Andrew Yarranton's classic work written in 1677.* Yarranton started life as an apprentice to a linen

* *England's Improvement by Sea and Land* (1677).

draper, and continued at the trade for some years, after which he took to travel and later joined the Army. In 1652 he entered an iron works, and next became interested in the problem of river transport. He surveyed many of the larger rivers of England, and developed schemes for rendering them navigable over great distances. In the course of his essay Yarranton regards the development of the manufacture of iron and linen as most probable and useful directions in which the wealth of England might be increased. He realized that efficient transport is essential to the development of manufacture. To quote from his own work: "That nothing may be wanting that may conduce to the benefit and encouragement of things manufactured, as in cheap carriage to and fro over England and to the sea at easy rates, I will in the next place show you how the great rivers in England may be made navigable . . . Thames as far as Oxford and Severn from Welshpool to Bristol." He then proceeds to indicate portions of these waterways that might be made navigable, and develops a line of communication, after which he shows that "these things being done all the great and heavy carriage from Cheshire, all Wales, Shropshire, Staffordshire and Bristol will be carried to London and re-carried back to the great towns, especially in the winter time, at half the rate that they now pay, which will much promote and advance the intended manufacture of linen." He goes on to show that he himself undertook the work of making the River Stour in Worcestershire navigable from Stourbridge to Kidderminster, necessitating an outlay of approximately £1,000. The scheme was dropped for want of additional money.

With the growth of trade arose the demand for improved means of internal transport, and most strongly in the north of England, where industry was developing most rapidly. Water communication was essential, as the bad state of the roads rendered road transport both slow and expensive. Manchester, the centre of the growing Lancashire trade, felt the lack of internal communication very keenly. The bad state of the roads impaired the city's food-supply, especially during the winter months, and such common articles of food as fruit and vegetables had to be borne into the city in packs slung across

the backs of horses. This method of transport rendered the produce so expensive as to be beyond the reach of the great mass of population. Boats, with the assistance of the tides, could only proceed up the Mersey as far as Warrington, and it was not until 1720 that an Act was obtained to make the Mersey and Irwell navigable from Liverpool to Manchester. The customary contrivances of weirs, locks, and flushes were employed to carry into effect what proved to be a very useful improvement. About the same time Acts were also passed permitting other river improvements in the same district, and these included the Weaver, the Douglas, and the Sankey navigations. The latter scheme is of special importance as it marks the commencement of the canal era, and the transition from the various river improvement schemes of the previous hundred years to the canal schemes of the middle of the eighteenth century. The original scheme of making the Sankey brook navigable, sanctioned by an Act of 1755, was abandoned, on account of the winding character of the stream and its liability to frequent flooding, in favour of a canal cut at a higher level than the stream in order to avoid the floods. The canal was provided with locks to overcome the fall of 90 feet in 12 miles to the Mersey, and the brook fed a pond placed at the highest level of the canal to maintain the water-supply.

"The immediate result of this pioneer canal was not only to provide a convenient coal-supply for Liverpool, but also in conjunction with the earlier rendering of the Weaver navigable to put the salt industry of Cheshire in direct water communication with the Lancashire coalfields. These advantages led (1) to a great expansion of the Cheshire salt industry; (2) to a substantial increase in the export of salt from Liverpool; and (3) to the ruin of the salt trade of Newcastle-on-Tyne, since, when the makèrs on the Weaver could readily get an abundance of coal, they, with their great natural stores of brine noted for its superlative quality and strength, had a great advantage over the makers on the Tyne, who obtained their salt from the waters of the sea."*

Although it has been stated that the Sankey brook scheme

* Pratt, *History of Inland Transport*, 166.

was the first example of a canal in the canal era, it should be recorded that in 1568 a canal was constructed by John Trew, a native of Glamorganshire. This canal, which was 3 miles long, connected Exeter with Topsham, and was cut when navigation by the River Exe between these two towns had become impossible owing to a weir being placed across the river by the Countess of Devon. This waterway contained the first lock to be constructed in this country, although at that period they were employed on some of the Italian canals.

The various river navigations mentioned above helped to improve communication between Liverpool and Manchester, yet much still remained to be done. Speaking of the Mersey and Irwell navigation, one writer observes: "The want of water in droughts, and its too great abundance in floods, are circumstances under which this, as most other river navigations, has laboured." Again: "It has been an expensive concern and has at times been more burdensome to its proprietors than useful to the public."* The Duke of Bridgewater, who had extensive collieries at Worsley, near Manchester, experienced great difficulty in securing suitable transport facilities for the conveyance of his coal to the people in Manchester. The proprietors of the Mersey and Irwell Navigation would not grant him special terms, charging the full 3s. 4d. per ton, even if the Duke used his own boats; and the only alternative was the seven miles of bad road that lay between Worsley and Manchester. Under these circumstances the Duke resolved on constructing a canal. Early in 1759 he applied to Parliament for powers to cut a canal from Worsley Mill to Salford in an easterly direction, and to Hollin Ferry on the Mersey in a westerly direction. Moreover, he agreed in the Bill not to charge more than 2s. 6d. per ton for coals transported on the canal from Worsley to Manchester, and further agreed to sell coal to the inhabitants of Manchester at half the price that was then prevailing. The advantages to the public of such a canal were made very clear, and the Bill passed without opposition in March, 1759. The Duke proceeded to Worsley to make arrangements for the construction of the

* Aikin, *Description of the Country from Thirty to Forty Miles round Manchester* (1795), 106.

canal, and consulted with his land agent, John Gilbert. Neither the Duke nor Gilbert were practical engineers, and in order to compensate for the lack of engineering knowledge, on the advice of Gilbert, the Duke called to his help James Brindley, who had earned a reputation in his own district for his practical engineering skill.

James Brindley was born in 1716 in a small cottage near Buxton, his father being little more than a cottier wresting a bare living from the soil. It is said that from his earliest childhood James, who was the eldest of the family, displayed a mechanical bias, and that one of his delights when a boy was to visit the local flour mill and examine the various water-wheels, cog-wheels, and other machinery, until he could reproduce them from memory in small pieces of wood, which he carved with his penknife. At the age of seventeen Brindley decided to bind himself to the trade of millwrighting, and became apprenticed to Abraham Bennett, a wheelwright and millwright of Sutton, near Macclesfield. The millwright's work of that period was very comprehensive, and he was required as necessity arose to work at the lathe, bench, and anvil. The journeymen with whom Brindley was put to work do not appear to have been very sympathetic towards him, and spent most of their time in the local tavern while Brindley was perforce required to undertake urgent repair work for customers who came into the shop. In this way Brindley was apparently often required to undertake work of a more difficult character than that appropriate to his stage of training, and seems to have earned a reputation from the journeymen of being "a bungling apprentice." Frequently, however, when Brindley was sent on to outside jobs in local mills, mill owners and engineers who came in contact with him agreed that there was capacity about the lad which his own master and journeymen had not discovered, and on occasions neighbouring millers, when sending for a workman to execute repairs, would specially request that the "young man Brindley" should be sent in preference to any other workman. On one occasion Brindley gave evidence of his determination and skill by walking, on his own initiative, from the shop in Macclesfield to a mill in which his master was installing machinery at Throstlenest,

on the River Irwell, near Manchester, in order to set right some defects in the machinery. After nine years at his trade as an apprentice, and two as journeyman, Brindley commenced business on his own account as wheelwright at Leek in 1742. The range of Brindley's activities at this period showed that he was employed in repairing and fitting up silk-throwing mills driven by water power at Macclesfield, and in repairing mills at Congleton, Newcastle-under-Lyme, and many places in the vicinity of Leek. During his work in the pottery district, Brindley came into contact with Mr. John Heathcote, who was then owner of the Clifton Collieries, near Manchester, and as a result of this meeting Brindley's assistance was requested in devising a method for clearing the Clifton coal mines of water. Brindley hit upon the solution of using the power in the fall of the River Irwell, which formed one boundary of the Clifton colliery estate, to pump water from the pits, and with this object in view he designed and constructed his first tunnel, 600 yards in length, through the solid rock. Through this tunnel the river impinged on a large water-wheel placed about 30 feet below the ground surface, and the water, after doing work on the wheel, passed to the lower level of the Irwell. Brindley next became associated with the building of a silk mill in Congleton, in Cheshire, where, owing to the incompetency of the consulting engineer, the original plan had to be abandoned. The inventive capacity and engineering skill of Brindley were evidenced in this work, and "in order that certain tooth-and-pinion wheels required in the mill machinery should fit each other with perfect precision, Brindley invented the machinery for their manufacture—a thing that had not before been attempted—all such wheels having, until then been cut by hand, at great labour and cost."* Brindley's machinery produced as much work in a day as had previously required a fortnight to complete.

It was shortly after this work that Brindley was approached by the Duke of Bridgewater to assist in the construction of the Worsley to Manchester canal. The Duke's own plan respecting this was to carry the level of the canal down into the River

* Smiles, *Lives of the Engineers*, "Brindley," 177.

Irwell by a series of locks, and then up again on the other side to the proposed level, and this scheme was sanctioned by the Act of 1759. Brindley proceeded to the site of the proposed canal, and after making a short survey, boldly recommended, in place of the Duke's design of a series of locks, that the canal should be carried right over the river and constructed at one uniform level throughout. Such a scheme involved entirely new features in engineering practice, and it was some considerable time before Brindley could convince the Duke of Bridgewater of the soundness and advantage of this scheme. The new plan required further Parliamentary sanction, which was obtained without opposition during the 1760 session. This formed one of the most ambitious parts of the scheme, and was achieved by the construction of the Barton Aqueduct, about 200 yards in length and 12 yards wide, the centre of which was supported by a bridge of three semicircular arches, the centre arch having a 63-feet span. In order to provide headroom for the largest barges to pass up the river the aqueduct was 39 feet above the river level. It was constructed of stone blocks, and the water-way was carried in a puddled channel to prevent leakage. The aqueduct was removed when the Manchester Ship Canal was constructed, but even at that time was in excellent condition. Shortly after the opening of the canal, Arthur Young,* who visited it, wrote: "The whole plan shows a capacity and extent of mind which foresees difficulties and invents a remedy before the evil exists. The connection and dependence of the parts on each other are happily imagined; and all exerted in concert to command by every means the wished-for success." The general importance of the Worsley to Manchester canal lay in the improved transport facilities it provided. Manchester, for the first time in its history, was regularly supplied with coal at low prices, the average price being reduced from 7d. to 3½d. per cwt. But the full advantages of this cheap supply of coal were not fully realized until some years after the completion of the canal, when, with the perfecting of the steam engine, extensive manufactures developed in the industrial north, particularly in and

* A. Young, *A Six Months' Tour through the North of England* (ed. 1771), III. 213.

around Manchester, and the demand for cheap coal supplies became the first essential to efficient manufacture.

We have referred to the need for improved means of communication between Liverpool and Manchester consequent upon the growing industry and commerce of these two towns, and under the circumstances the Duke of Bridgewater projected a canal which would join the Worsley canal at Longford Bridge and connect with the Mersey at Runcorn, the total length of the canal being about 24 miles. After considerable opposition the Bill for the construction of the Bridgewater Canal was passed in March, 1762, and forthwith Brindley proceeded to cut the canal. The most remarkable engineering feat on the canal was the flight of locks at Runcorn, but it was not until 1773 that these were completed, whereas the canal up to Runcorn was opened to traffic in 1767. The work proved much more expensive than had been anticipated, and the Duke had to borrow £25,000 from Messrs. Childs, the London bankers. In all, a total of some £220,000 was spent by the Duke on his two canals. The necessity of a flight of locks at Runcorn was occasioned by the difference in level between the canal and the River Mersey, and the type of lock constructed by Brindley was the first of its kind to be adopted in England. A lock is defined as "the connecting part between two reaches of a canal that are on different levels, and this part which is called the 'chamber' can be made to coincide with either the upper or lower level by means of two pairs of gates, one at each end of the chamber, in which gates, or through the side walls of the chamber, small sluices, are provided by which water can be let in from the higher level to fill the chamber to the upper level, the lower gates being close shut, or to empty the same to the level of the lower reach, the upper gates being shut. On the arrival of the vessel at the lock from the lower level there is no difficulty, if the lock is unoccupied, in opening the lower gates, because the water in the chamber is level and at rest. The lower gates are then shut, the water let in through the sluices from the higher reach, and the vessel rises to the higher level, when the upper gates are opened, the pressure of the water being equal on both sides of them."*

* Forbes and Ashford, *Our Waterways*, 100.

In 1772 the Duke improved the usefulness of the Manchester to Runcorn canal by establishing a service of passenger boats, each accommodating sixty passengers, on which a charge of 1s. per passenger was made for a journey of 20 miles. These boats were later superseded by larger ones holding as many as 120 passengers. Each boat was "provided with a coffee-house kept by the master; wherein his wife served the company with wine and other refreshments."* One of the most important effects of the Manchester to Liverpool canal was to divert traffic to Liverpool. A considerable amount of export trade which had previously gone from Manchester to Bristol now went to Liverpool, and, moreover, it enabled Manchester manufacturers to obtain readily raw materials from Liverpool. It also enabled Manchester to obtain supplies of coal from a much wider area than it had formerly attacked, and in this way to supplement the supplies of cheap coal from Worsley.

Even before the Bridgewater Canal was completed Brindley was engaged in the design of a Grand Trunk Canal to connect the Mersey with the Trent, and each with the Severn, and so provide a through line of water communication between Liverpool, Hull, and Bristol. The Act of 1766, giving the necessary powers for the construction of this canal, provided a waterway through the Potteries and was actively supported by Josiah Wedgwood, who cut the first sod for the canal. The nature of the conditions under which the Trent and Mersey section of the Grand Trunk system was made afforded an early example of the physical difficulties attendant on canal construction in England, which were to be a leading cause of the decline of canals as soon as the greater advantages of the railway and the locomotive had been established. Canals were superior to rivers in so far as they could be taken where rivers did not go, and could be kept under control in regard to water-supply without the drawbacks of floods or droughts, of high tides, or of being silted up by sand or mud. It is, indeed, reported that when, after he had made a strong pronouncement in favour of canals, James Brindley was asked by a Parliamentary Committee, "Then what do you think rivers are for?" he replied, "To supply canals with water." On the other hand, "between the

* Macpherson, *Annals of Commerce*, III. 527 n.

Mersey and Trent there were considerable elevations which formed very difficult country for water transport. These elevations had to be overcome by the gradual rising of the canal, by means of locks, to a certain height, by the construction, at that point, of a tunnel through the hills, and by a fresh series of locks on the other side to allow of a lower level being reached again. The rise of the Trent and Mersey Canal from the Mersey to the summit at Harecastle, near the Staffordshire Potteries, was 395 feet, a final climb of 316 feet being made by means of a flight of 35 locks. Through Harecastle Hill there was driven a tunnel a mile and two-thirds in length and with a height of 12 feet and a breadth of 9 feet 4 inches.* South of this tunnel the canal descended to the level of the Trent, a fall of 288 feet, by means of 40 locks. In addition to this, the canal in its course of 90 miles had to pass through four other tunnels, and be carried across the River Dove by an aqueduct of 23 arches, and at four points over windings of the Trent, which it followed to its junction therewith at Wilden Ferry. These engineering difficulties were overcome by James Brindley, and the canal was opened for traffic in 1777."†

The opening of the Grand Trunk and other canals connecting with it resulted in marked reductions in the cost of carriage, as is shown in the following figures:‡

COST OF GOODS TRANSPORT PER TON.

Between	*By Road.*			*By Water.*		
	£	s.	d.	£	s.	d.
Liverpool and Etruria	2	10	0		13	4
,, ,, Wolverhampton	5	0	0	1	5	0
,, ,, Birmingham	5	0	0	1	5	0
Manchester and Wolverhampton	4	13	4	1	5	0
,, ,, Birmingham	4	0	0	1	10	0
,, ,, Lichfield	4	0	0	1	0	0
,, ,, Derby	3	0	0	1	10	0
,, ,, Nottingham	4	0	0	2	0	0
,, ,, Leicester	6	0	0	1	10	0
,, ,, Gainsborough	3	10	0	1	10	0
,, ,, Newark	5	6	8	2	0	0

* "Subsequently supplemented by a tunnel of larger dimensions [illegible] constructed by Telford." † Pratt, *op. cit.*, 173, 174.
‡ Baines, *History of Liverpool*, 439, 440. Figures quoted from Williamson's *Liverpool Advertiser*, August 8, 1777.

Thus the reduction in some cases amounted to more than half the previous cost by pack horses or road waggon. The introduction of canals was the direct cause of many changes consequent upon the reduced cost of transport of raw material and finished goods. It was exceedingly difficult to provide adequate food reserves for the large populations of the growing manufacturing towns in the winter owing to the difficulty of bringing large quantities of food from the country districts along the almost impassable roads of these times. With the development of canals it became possible to feed these populations with a minimum of effort and at a normal cost. The facilities which were afforded for the conveyance of goods from the country districts in the interior to the various ports were a distinct incentive to the development of the latter. A redistribution of the population was made possible by the various canal systems as the people were able to move from the wooded and peat districts now that coal could be easily transported from place to place at a reasonable charge. Farmers were provided with a wider market for their produce, and in this way the growth of large farms was stimulated. The manufacturing towns were able to extend much more rapidly than hitherto had been possible.

The Grand Trunk Canal proved to be the success which Brindley had anticipated, and numerous other canals were constructed as a result. Important among these was the Wolverhampton Canal connecting the Trent with the Severn, and now known as the Staffordshire and Worcestershire Canal. In 1768 the construction was authorized of three other canals which Brindley had designed: the Coventry Canal, connecting the Grand Trunk system with London; the Birmingham Canal; and the Droitwich Canal to connect that town by a short branch with the River Severn. During the latter part of his life Brindley was consulted respecting many canals which were designed by other engineers. Among these were the Leeds and Liverpool Canal, the Calder Navigation, the Forth and Clyde Canal, the Salisbury and Southampton Canal, the Lancaster Canal, and the Andover Canal. The Leeds and Liverpool Canal was of great importance from an industrial standpoint, for it connected Lancashire and Yorkshire, and overcame the

natural barrier which the Pennines presented. In constructing this canal, notable engineering works were undertaken, and included a tunnel 1,640 yards long, which occupied five years in the making, and pierced the Foubridge Hills; an aqueduct bridge of seven arches to cross the Aire; and an aqueduct to carry the canal over the Shipley valley. The total length of the work was 127 miles, with a fall of 525 feet on the Lancashire side, and 446 feet on the Yorkshire side of the central level. The entire construction of the navigation lasted forty-one years, and cost £1,200,000.

The success which attended the Bridgewater Canal and the Grand Trunk Canal had the effect of inspiring the public with great confidence in this new type of engineering enterprise. Fulton,* writing in 1796, says: "So unacquainted were the people with the use of canals, and so prejudiced in favour of the old custom of river navigation, that the undertaking was deemed chimerical, and ruin was predicted as the inevitable results of his Grace's labour. . . . Yet it was not long finished when the eyes of the people began to open; the Duke could work on his canal when floods or dry seasons interrupted the navigation of the Mersey; this gave a certainty and punctuality in the carriage of merchandise, and ensured a preference to the canal; the emoluments arising to the Duke were too evident to be mistaken; and perseverance having vanquished prejudice, the fire of speculation was lighted, and canals became the subject of general conversation." This "canal mania" occupied the years 1791-94, and during these four years no fewer than eighty-one Canal and Navigation Acts were passed. Many of these projects had little, if any, practical application, and many investors were ruined.

Brief reference must now be made to the work of Telford, Smeaton, and Rennie, in the construction of canals. Smeaton was responsible for the construction of the Forth and Clyde Canal, respecting which, as we have already noted, Brindley was consulted, though he was too much occupied with other affairs to undertake the work. The Act empowering its construction was passed in 1768. The canal was 38 miles long, and involved the construction of thirty-nine locks to the

* Fulton, *A Treatise on the Improvement of Canal Navigation.*

157 feet summit. Financial difficulties were experienced, and the work stopped before the Clyde was reached. It was not resumed until twenty years later, when, in 1790, it was finished by Whitworth, one of Brindley's pupils. After Smeaton's retirement from business, in 1791, Rennie was consulted respecting several canal projects. Important among these was the Kennet and Avon Canal, which he subsequently constructed, and which has been pronounced as one of the most efficiently constructed canals in the country. It covered a total length of 57 miles, and included seventy-nine locks. Rennie was later engaged in the construction of the Rochdale Canal, designed to establish an east to west line of communication in the industrial north, which would at the same time avoid the circuitous route of the Leeds and Liverpool Canal. The Rochdale Canal rises from its start at Manchester by a succession of locks to a level 438 feet above the level at Manchester, and descends to the River Calder at Sowerby Bridge, from which point the river is navigable to the Humber. The Lancaster Canal was also constructed under the direction of Rennie, and provided a means of communication between the coal district of Wigan and the lime district near Lancaster, Burton, and Kendal, also connecting these towns with Liverpool and Manchester. A survey was made by Brindley in 1772, but nothing was done until twenty years later, when a company was formed with Rennie as engineer. The canal was $77\frac{3}{4}$ miles in length, and crossed the Lune at Lancaster by an aqueduct consisting of five semicircular arches of 75 feet span, the whole length being 600 feet.

Telford's first canal undertaking was the Ellesmere Canal, sanctioned by Act of Parliament in 1793, which linked up Ellesmere, Whitchurch, Chester, Shrewsbury, and Oswestry by a series of navigations proceeding from the River Dee, and having a total length of 112 miles. Telford's knowledge of masonry enabled him to undertake this part of the work without difficulty, but he conferred with William Jessop to supplement his own small experience of earthwork. To avoid the expense of a series of locks in carrying his canal from the Dee valley to that of the Ceriog, Telford constructed two large aqueducts, one at Chirk, and one at Cysylltan, which have

been described by Phillips as "among the boldest efforts of human invention in modern times."* The aqueducts were very expensive, but "Telford, like Brindley, thought it better to incur a considerable capital outlay in maintaining the uniform level of the canal, than to raise and lower it up and down the sides of the valley by locks at a heavy expense in works, and a still greater cost in time and water." In this connection it should be noted that locks provide the method most generally adopted by which two different levels on a canal may be bridged. Two other methods, however, exist, in the inclined plane and the hydraulic elevator. The inclined plane was used in the construction of the Ketling Canal in Shropshire in 1789, and consists of a tank filled with water into which the canal boat is placed, and which is then drawn up an inclined railway to the second level. In some cases the boat is withdrawn from the water and dragged up an inclined railway while placed in a cradle. The hydraulic elevator is a more powerful device, and was first adopted in this country in 1874-75 by the Weaver Trustees at Anderton. "This lift raises and lowers the canal boats through a height of 50 feet between the River Weaver and the Trent and Mersey Canal, being connected with the latter by a wrought-iron aqueduct. The boats are enclosed in a water-tight trough, and remain afloat during the whole operation . . . the caissons or troughs are capable of holding two of the narrow boats in use on the canal, and the operation of entering, lowering, and opening the gates and passing out can be performed in from ten to twelve minutes. The waste of water is 6 inches deep over the area of the trough, $\frac{11}{12}$ of the stroke being performed by means of the weight of this water, and the remaining power being supplied by a small engine working an accumulator. As the lift has two troughs which are in equilibrium until the 6 inches extra of water is put in, one always ascending and the other descending, it is ready for either up or down traffic, and when vessels from both sides arrive at once it acts as a double lock."†

Telford acted as chief engineer in the construction of the

* Phillips, *A General History of Inland Navigation, Foreign and Domestic* (1803), 299.

† Saner, at Conference on Inland Navigation, Birmingham, February, 1895.

Caledonian Canal, while Jessop served as consulting engineer. The work was commenced in 1804, and involved the construction of a large number of culverts, tunnels, and underbridges to accommodate the numerous mountain streams that passed under the canal. Eight public road bridges made of cast iron with a horizontal swing had to be provided and the whole work was skilful in both design and execution. Unfortunately, the canal proved a commercial failure, although this in no way should detract from the honour due to the engineer. Telford constructed or improved several canals, including the Gloucester and Berkeley Canal in 1813, the Grand Trunk Canal and the Birmingham Canal in 1824, and the Macclesfield, Birmingham, and Liverpool Junction Canal in 1825. He also built a new tunnel at Harecastle in 1824-27, supplementing the earlier one of Brindley, which became inadequate for the increased traffic. The new tunnel was 2,926 yards in length, and was made by the sinking of fifteen pit shafts; its breadth was 14 feet, of which 4 feet 9 inches was occupied by a towing path.

Two forms of water communication between Liverpool and Manchester have already been considered. The first was the Mersey and Irwell navigation, a long and devious route which included nine locks between Manchester and Warrington; the second, the extension of the original Worsley to Manchester Bridgewater Canal, whereby communication was established with the Mersey at Runcorn. Neither of these waterways could accommodate barges of more than 50 tons burden. Later, the Liverpool and Manchester Railway afforded greater facility for transport between these two towns, but high freightage charges on the railway combined with heavy dock dues at Liverpool suggested to Manchester merchants the possibility of establishing a waterway from Manchester to the sea that would accommodate the larger ocean-going vessels, so that cotton, timber, and other raw materials could be brought direct to Manchester without any transhipment *en route*. Although a scheme had been prepared as early as 1825, it was not until 1882 that plans were discussed that later matured to a practical outcome. Two schemes were proposed, one by Mr. Hamilton Fulton, and the other by Mr. (later Sir) E. Leader

Williams, the latter scheme being finally accepted. When Parliamentary powers were sought for the execution of the work, great opposition was encountered from bodies having vested interests, notably the railway company, the Liverpool Dock authorities, and the canal and river navigation proprietors whose properties lay between Liverpool and Manchester. To appease Liverpool and the railway companies, the line of the proposed canal had to be altered somewhat, and the Bridgewater Canal was bought for a sum of £1,786,313, and became part of the Ship Canal system. Out of a total expenditure of £15,173,402, as much as £1,214,451 was paid for land and compensation to various authorities, in addition to the amount already noted to the Bridgewater Canal Company. Finally, the Bill sanctioning the scheme was passed in the 1885 session, although work was not begun until November, 1887, owing largely to difficulties that were experienced in raising the requisite capital. The total length of the canal is 35½ miles, and is divided into three main sections. The first section, 12¾ miles long, from the Mersey entrance to the canal at the Eastham docks to Runcorn, runs near or through the Mersey estuary, and is entered by the deep channel of the Sloyne in the Mersey which provides a safe and sheltered entrance, even at low tides. There are three parallel entrance locks by which the level of the water in the canal is maintained at approximately high-water level. In those parts of this section where the canal is coincident with the estuary of the Mersey embankments are constructed to keep the water in at low tides. The second section of the canal is from Runcorn to Latchford, a distance of 8¼ miles, where it is inland, but in which the level of the water, as in the first section, is raised by the tides. The third section, 14½ miles long, runs from Latchford, where the locks stop the tidal action, to Manchester, and is fed by the waters of the Mersey and Irwell. In the construction of the canal 54 million cubic yards of earth were excavated, the greater portion of which was performed by eighty steam navvies and canal dredgers; upwards of 17,000 men were engaged on the work.

Perhaps the most conspicuous engineering feature of the canal was the swing aqueduct at Barton, designed to carry the

Bridgewater Canal. Brindley had, 156 years previously, constructed the first fixed aqueduct to carry the Bridgewater Canal over the River Irwell, but it was built so low that only barges could pass on the river under it. A problem arose, therefore, to maintain the Bridgewater Canal, while at the same time enabling the largest steamers to pass up the Ship Canal, which at this part coincided with the Irwell. Locks were practically prohibitive because the Bridgewater Canal is on one level as far as Runcorn, and the water-supply available was only sufficient to make good the wastage at the Runcorn locks. The difficulty, however, was overcome by Sir E. Leader Williams, the engineer of the canal, who constructed a swing aqueduct, which, when open, allows the Ship Canal traffic to pass, and when closed allows the Bridgewater Canal traffic to pass. The aqueduct is described by Sir E. Leader Williams as follows: "The water in the swing portions of the aqueduct when opened is retained by closing gates at each end, similar gates being shut at the same time across the fixed portion of the aqueduct. The swing portion is a large steel trough carried by side girders 234 feet long by 33 feet high in the centre, tapering up to the ends; the waterway is 19 feet wide by 6 feet deep. The whole rests on a central pier with similar arrangements to the largest swing bridges on the canal; it has two spans over the ship canal of 90 feet each. The swing aqueduct is worked by hydraulic power, and has never given any trouble in working, even in times of severe frost. The weight of the movable portion, including the water, is 1,600 tons."* The canal was opened on May 21, 1894. Its commercial and economic results have been pronounced, and may be summarized as follows: "The traffic in the canal gradually increased from 925,659 tons in 1894 to 2,778,108 tons in 1899, and 5,210,759 tons in 1907. After its opening considerable reductions were made in the railway rates of carriage and the charges at the Liverpool docks, in order to compete with water-borne traffic at lower rates. The result has been of great advantage to the trade of Lancashire and the surrounding districts, and the saving in the cost of carriage, estimated at £700,000 a year, assists manufacturers to meet the competition of their foreign opponents,

* *Encyclopædia Britannica*, "Canals."

who have the advantages of low rates of carriage on the improved waterways of America, Germany, France, and Belgium. Before the construction of the canal, large manufacturers had left Manchester to establish their works at ports like Glasgow, where they could save the cost of inland carriage. Since its opening, new industries have been started in Manchester, and along its banks, warehouses and mills that were formerly empty are now occupied."*

The marked decline in the use of canals in this country calls for some comment. It was due to many causes, among which was the failure to compete with the other methods of transport which were introduced during the nineteenth century whereby the time of transit was reduced, greater punctuality secured, and better co-ordination between systems was effected. Again the coasting steamer, by reason of its larger capacity, afforded the same advantages over the small capacity barge as the barge had in its day over the pack horse. There were only a few canals which were able to compete satisfactorily with the railways, or were in the position of being links between railway systems; these latter were purchased and developed by the railway companies, and in this way were removed from the field of competition. The canals were organized under a large number of companies, and it proved impracticable to negotiate agreements by which improvements could be carried out over a whole length, because one company by its retrograde policy nullified the efforts of the more enlightened companies. Warehouses and buildings had been closely crowded upon the canal routes in the various towns, and although expansion of routes was most needed in the towns, these factors rendered the cost prohibitive. Other factors also caused the failure of the canal system, apart from financial and commercial reasons—namely, engineering defects. One of the commonest defects in canal construction is laying it at too high a level, where there is no regular water-supply to make good losses due to lockage. "Lockage" is the term used to refer to the waste of water that takes place on a canal in moving boats, through the medium of locks, from one level to another. It arises from the fact that "up traffic consumes more water than down, for

* *Ibid.*

the reason that an ascending vessel displaces a volume of water equal to its submerged capacity; the water so displaced flows into the lower reach of the canal, and the lower gates are closed; the vessel is then raised, and on passing into the higher reach of the canal, its displacement loss on entering is supplied by water drawn from the higher reach. A descending vessel similarly displaces a volume of water equal to its submerged capacity, but the water in this case flows back into the higher reach, where it is retained when the gates close."* The Sheffield and Tinsley Canal was constructed at too high a level, much above the level of the River Don, which would have supplied it with water. The result was that not only was a great amount of time wasted in passing through the locks, but great expense was incurred in pumping water from the coal-pits to make up the losses in the normal working of the canal. There were twelve locks within the short distance of 3 miles, and pumping cost the concern £450 per annum. Very little use was made of the canal by carriers. The Monmouthshire Canal provides another example of canal failure on account of unfortunate engineering design. One branch of the canal, 8 miles long, had thirty-two locks to overcome a drop in level of 365 feet; and another branch, 11 miles long, had forty-two locks to overcome a fall of 447 feet. The size of the canal barge was also strictly limited by the shallowness of the canals, and this, coupled with the great delay encountered in passing through the great number of locks, spelt ruin for the canal. On the Leeds and Liverpool Canal, boats, especially during the summer time, had frequently to wait two or three days before they could pass through certain locks. The Huddersfield Canal, apart from the lack of water in dry seasons, contained a tunnel 5,720 yards long, which vessels could only enter every twelve hours, and these two conditions introduced great delays that inconvenienced carriers.

The canal situation was well reviewed by Nicholas Wood, who, writing in 1838, said: "Canals ever since their adoption have undergone little or no change; some trivial improvements may have been effected in the manner of passing boats from one level to another, and light boats have been applied for the

* *Encyclopædia Britannica*, "Canals."

conveyance of passengers; but in their general economy they may be said to have remained stationary. Their nature almost prohibits the application of mechanical power to advantage in the conveyance of goods and passengers upon them; and they have not therefore partaken of the benefits which other arts have derived from mechanical science."* Within recent years suggestions have been made to revive the canal system of the country by applying electric power for its working. Several canals on the Continent of Europe are operated in this manner, the usual method being to use electric tractors which run on rails along both banks of the canal and take electric power from overhead wires. In such cases electrical power is also used for operating the lock gates, and supplying power for other purposes along the canal. In this country, however, the horse or mule walking along a tow-path remains the chief motive power on the smaller canals. On ship canals either steam tugs are used or vessels proceed under their own steam. The maximum speed at which boats can safely be propelled along canals is about 3½ miles per hour; above this speed damage is done to the banks of the canal by the force of the back wash of the boats, and special protecting walls of masonry or concrete have to be constructed. Steam towage was first adopted on the Forth and Clyde Canal in 1802, when a tug boat which drew two canal barges was fitted with steam engines constructed by William Symington, one of the early inventors of the steamboat. A distance of 19½ miles was covered in six hours, and having regard to the fact that the journey was accomplished in the teeth of a high wind, it was a creditable performance. In 1789 Symington tried the experiment of fitting the barges with small steam engines, and many barges equipped in this manner are now running.

* Wood, *Practical Treatise on Railroads* (1838), 16 and 17.

CHAPTER V

ROADS AND BRIDGES

Reference has been made in an earlier chapter to the engineering work of the Romans in Britain, an outstanding feature of which was the building of many excellent roads for military purposes. The majority of the Roman roads gradually fell into disrepair after the legions withdrew in A.D. 411. Of early English roads we have but little information. It is clear that under the manorial system the lord of the manor, while responsible for the upkeep of the roads, delegated his responsibility to his tenants, and failure to carry out necessary repairs was investigated by the manorial courts. The Church also took an active interest in the maintenance of thoroughfares, and at one period hermits frequently took up their habitation in cells along the main highways, busying themselves with the upkeep of the road, and receiving alms from the passers-by. The first toll bar—a swing barrier set up across a highway—was erected in this country by a hermit, who had royal sanction to collect a tax from persons using the road, which he kept in good repair. It is described in the decree made by Edward III. in 1346: "Our well beloved William Phelippe the hermit" is authorized "to set up a toll bar on the lower slope of Highgate Hill on the north side of London and levy tolls for the repair of the Hollow Way," from "our people passing between Highgate and Smithfield." The contribution which the Church at this period made to the maintenance of roads is indicated by Jusserand: "The roads in England would have been entirely impassable if the nobility and the clergy, that is to say, the whole of the landed proprietors, had not had an immediate and daily interest in possessing passable roads."* However, the decline of the religious orders in the fifteenth century, followed by the dissolution of the monasteries in the sixteenth,

* Jusserand, *English Wayfaring Life in the Middle Ages,* 82.

brought to an end the interest of the clergy in road maintenance and "the roads suffered because the available wealth of the Kingdom was being drained for the French wars and there was no one with sufficient public spirit to take up the matter in earnest."*

The early English road was very different from the well-defined and metalled strip of land with which we to-day are familiar. The road in the fifteenth century was but a right of way, or, as a lawyer of that period states, "a perpetual right of passage in the sovereign for himself and his subjects, over another's land." Usage gradually turned these rights of way between villages into beaten tracks, and it is not difficult to realize that such tracks would become practically impassable in the winter. One authority† speaks of the medieval roads in the following terms: "With the exception of the principal roads communicating with the important sea ports and fortresses of the Kingdom (probably the four great roads formed either by the Romans or Saxons) the other highways were but tracks over unenclosed ground, where the passenger selected his path over the space which presented the firmest footing, and fewest impediments, as is the case in the present day in forests and wastes in remote situations." In some parts of England this state of affairs continued as recently as the eighteenth century, for in Cumberland, we are told, "in the spring of the year, the surveyor used to call on the people to go with him to open the tracks over the common, from which the old tumble wheel-carts of the country had been excluded during the winter; for in 1792 the principal part of the corn was conveyed to market on the backs of horses."‡

One of the earliest statutes relating to the roads of England was the Statute of Winchester in 1285, which was designed more for the protection of travellers from robbers that infested the highways than to secure improvements in the construction of the roads. It required "that highways leading from one

* Cunningham, *The Growth of English Industry and Commerce,* Middle Ages, 451.

† Delany, *The General Turn-Pike Acts.*

‡ Speech by W. Blamire in the *Cumberland Pacquet,* February 2, 1830. Quoted by Webb, *The Story of the King's Highway,* 6.

market town to another shall be enlarged where as the bushes or dykes be so that there be neither dyke nor bush whereby a man may lurk or do hurt within 200 feet of the one side, and 200 feet of the other side of the way." In Henry VIII.'s reign, numerous statutes relating to ill-conditioned roads in Sussex and the Weald of Kent were passed. From this legislation, it would appear that when roads, through much usage, became impassable, new tracks were struck out adjoining the old ones. One Act of this period states: "Many of the wayes in the wealds are so deep and noyous by wearing and course of water and other occasions that people cannot have their carriage or passages by horses uppon or by the same but to their great paynes, perill and jeopardie." Statutes provided that, with the consent of two justices and twelve members of the hundred, owners might shut ill-conditioned roads and establish new ones. The most important Act of early times affecting the roads was passed in the reign of Queen Mary (1555). This Act is of special interest as it charged the parish with the responsibility for road maintenance, and gave it powers to recruit compulsory labour for this work. It constitutes the basis of the modern legislation relating to road maintenance, except that compulsory labour has been abolished and money payment levied. The preamble declared that roads had become "both very noisome and tedious to travel in and dangerous to all passengers and carriages." It was therefore ordered that constables and churchwardens should, during Easter week in each year, call together a number of parishioners, and choose one or more persons to serve gratuitously as Surveyors of Highways for the ensuing year. "But except for the individual who found himself thrust into an unpaid and onerous office, this was the easiest part of the task. All the manual labour, tools, and horses and carts needed for repairing the roads, had to be furnished gratuitously by the parishioners themselves. 'Every person, for every ploughland in tillage or pasture' that he occupied in the parish—defined subsequently as a holding of £50 annual value—and also 'every person keeping a draught [of horses] or plough in the Parish,' had to provide and send 'one wain or cart furnished after the custom of the country, with oxen, horses, or other

cattle, and all other necessaries meet to carry things convenient for that purpose, and also two able men with the same.' Finally, 'every other householder, cottager, and labourer, able to labour, and being no hired servant by the year,' was either to go himself to work or to send 'one sufficient labourer in his stead.' All these teams and labourers had annually to appear on the roads on the date and at the hour fixed by the Surveyor, there to work under his direction for eight hours on four, and afterwards on six, consecutive days."* The persons chosen as surveyors of highways were usually extremely incompetent. They lacked training and experience both in regard to road construction and repair. "If they opened the tracks over the common lands once a year, and heaped up earth on the more frequented roads when the ruts became exceptionally deep, they considered their duty well discharged."† Despite the far-reaching provisions of the Act of 1555, contemporary writings show that very little progress was made, and that the Act was not always enforced. One writer in the opening years of the reign of William and Mary remarks that "the drowsy heads of the slumbering statutes made for the repairing and amendment of highways" needed to be "roused up" by a new Act, that of 1691.‡ This new Act contains the first reference to minimum requirements respecting road widths, and provides that the surveyors shall make every cart-way leading to any market town 8 feet wide at least, and as near as may be even and level, and that "no horse causey shall be less in breadth than three feet."

In response to the demand for improved roads, a new principle of road maintenance came to be adopted in the construction of turnpike roads, first authorized in 1663 by an Act of Parliament. According to this Act, persons using the road were required to pay a toll, the tolls being expended on road maintenance. The first turnpike road where toll was taken intersected the counties of Hertford, Cambridge, and Huntingdon.§ Considerable opposition was displayed by the public to the construction of toll bars and to the system which

* Webb, *The Story of the King's Highway*, 15. † *Ibid.*, 32.
‡ Quoted *ibid.*, 22. § Lardner, *Railway Economy*, 32.

it inaugurated. The main cause of the opposition is aptly expressed by Whittaker: "To intercept an ancient highway, to distrain a man for the purchase of a convenience which he does not desire, and to debar him from the use of his ancient accommodation, bad as it was, because he will not pay for a better, has certainly an arbitrary aspect, at which the rude and undisciplined rabble of the north would naturally revolt."* Furthermore, the establishment of the turnpike system afforded opportunities for malcontents for stirring up strife in the country, by assuring people that the Government intended withdrawing from the populace liberty to freely move along the roads of the country. Active opposition to the tolls took place in all parts of the country. In 1749 the *Gentleman's Magazine* gave an account of riots in Gloucestershire and Somerset, where for twelve days a miniature battle raged. The destruction of the gates at Bedminster by "great numbers of people" was followed by the blowing up with gunpowder of toll-gates near Bristol. Night after night men from the towns and villages, armed with spears, pitchforks, axes, and guns, some disguised as women, demolished toll-gate after toll-gate, until by August 3 (rioting commenced on July 24) practically no toll-gate was left in the Bristol district. It was not until a strong body of troops arrived that the riot was finally quelled. Four years later a serious turnpike riot broke out in Yorkshire, being especially serious in the neighbourhood of Leeds. As many as twelve toll-gates were demolished in a week. Before the riot subsided troops were summoned, resulting in the killing of two or three persons and the wounding of many more. Evidence to show that in many roads little improvement took place may be cited from several sources. A writer in the *Gentleman's Magazine* for November, 1752, confirms that the roads from London to Land's End were still "what God left them after the flood." In Sussex the roads appear to have been particularly bad. On the occasion of the visit of Charles III. of Spain to London in 1702—the year of Queen Anne's accession to the throne—Prince George of Denmark went from Windsor to Petworth to meet him, and in recounting the incidents of the journey, which was of

* Whittaker, *Loides and Elmete*, 82.

40 miles distance, says: "We set out at 6 in the morning . . . and did not get out of the carriages (save only when we were overturned or stuck fast in the mire) till we arrived at our journey's end. 'Twas a hard service for the Prince to sit fourteen hours in the coach that day without eating anything, and passing through the worst ways I ever saw in my life. . . . The last nine miles of the way cost us six hours to conquer them." Again, Defoe states that the transport of timber by road from Lewes to Chatham has occupied as long as two or three years; the method adopted appears to have been to drag the trunk of the tree by a large team of oxen, suitably mounted on a rough form of carriage, for a short distance, the log being then left by the wayside to be dragged a similar short distance farther on by another team, and so on till the journey's end.*

The most striking accounts of the state of the roads at this period are given by Arthur Young,† who, writing in 1770, relates *inter alia* the following experience: "To Warrington. Turnpike. This is a paved road, and most infamously bad. . . . Tolls had better be doubled and even quadrupled than allow such a nuisance to remain." "From Dunholm to Knotsford. Turnpike. It is impossible to describe these infernal roads in terms adequate to their defects. Part of these six miles I think are worse than any of the preceding." "To Newcastle. Turnpike. This, in general, is a paved causeway, as narrow as can be conceived, and cut in perpetual holes, some of them two feet deep, measured on the level; a more dreadful road cannot be imagined; and wherever the country is in the least sandy the pavement is discontinued, and the rutts and holes most execrable. I was forced to hire two men at one place to support my chaise from overthrowing, in turning out from a cart of goods overthrown and almost buried. Let me persuade all travellers to avoid this terrible country, which must either dislocate their bones with broken pavements or bury them in muddy sand." Young shows that the roads in the south of England were no better than those

* Defoe, *A Tour through the Whole Island of Great Britain* (ed. 1738), I. 196.

† Young, *Six Months' Tour through the North of England* (1770; 2nd edition), IV. 431 *et seq.*

in the north. "Of all the roads that ever disgraced this Kingdom in the very age of barbarism, none ever equal that from Billericay to the King's Head at Tilbury. It is for near twelve miles so narrow that a mouse cannot pass by any carriage; I saw a fellow creep under his wagon to assist me to lift, if possible, my chaise over a hedge. . . . I must not forget the eternally meeting with chalk wagons, themselves frequently stuck fast till a collection of them are in the same situation that twenty or thirty horses may be tacked to each to draw them out one by one."* Of the Norfolk roads he speaks as follows: "For ponds of liquid dirt and a scattering of loose flints, just sufficient to lame every horse that moves near them, with the addition of cutting vile grips across the road under pretence of letting water off, but without the effect, altogether render at least 12 out of these 16 miles as infamous a turnpike as ever was travelled."† It would appear, therefore, that the Turnpike Acts accomplished very little permanent improvement in the state of the roads. We must assume, however, that this was the case only in certain parts of the country, for there is little doubt that in the aggregate the turnpike system made a distinct contribution to the social and economic progress of England, and that trade and commerce were stimulated as a result of the improved means of intercommunication between the various parts of the country. Writing in 1767, Henry Homer observes: "Our very Carriages travel with almost winged expedition between every Town of consequence in the Kingdom and the Metropolis. By this, as well as the yet more valuable Project of increasing the inland navigation, a Facility of Communication is soon likely to be established from every part of the Island to the sea, and from the several places in it to each other. Trade is no longer fettered by Embarrasments, which attended our former Situation. Dispatch, which is the very life and soul of Business becomes daily more attainable by the free Circulation opening in every Channel, which is adopted to it. Merchandise and Manufactures find a ready conveyance to the Markets. The natural Blessings of the Island are shared by the Inhabitants

* Young, *Six Weeks' Tour through the Southern Counties of England and Wales* (ed. 1772), 88.

† *Ibid.*

with a more equal Hand. The Constitution itself acquires Firmness by the Stability and Increase both of Trade and Wealth which are the Nerves and Sinews of it. In consequence of all this, the Demand for the Produce of the Lands is increased; the Lands themselves advance proportionately both in their annual Value and in the Number of Years' purchase for which they are sold, according to such value. . . . There never was a more astonishing Revolution accomplished in the internal System of any Country than has been within the Compass of a few years in that of England. The carriage of Grain, coal, Merchandise, etc., is in general conducted with little more than half the number of Horses with which it formerly was. Journies of Business are performed with much more than double Expedition. Improvements in Agriculture keep pace with those of Trade. Everything wears the face of Dispatch; every Article of our Produce becomes more valuable; and the Hinge, upon which all these Movements turn, is the Reformation which has been made in our Public Roads."*

Other advantages of the turnpike system are described by Daniel Defoe, who analyzes the situation in the following interesting manner: "The Benefit of these Turn-pikes appears now to be so great, and the People in all Places begin to be so sensible of it, that it is incredible what effect it has already had upon Trade in the Counties where the Roads are completely finished; even the Carriage of Goods is abated, in some places, 6d. per hundred Weight, in others 12d. per hundred, which is abundantly more Advantages to Commerce than the Charge paid amounts to. . . .

"Besides the benefits accruing from this laudable Method we may add, the Conveniency to those who bring fat Cattle, especially Sheep, to London, in the Winter from the remoter Counties of Leicester and Lincoln, where they are bred: For before, the County Graziers were obliged to sell their Stocks off in September and October when the Roads began to be bad, and when they generally sell cheap; and the Butchers and Farmers near London used to engross them, and keep them

* Homer, *An Enquiry into the Means of Preserving Public Roads* (1767), 6 *et seq.*

till December and January, and then sell them, though not an Ounce fatter than before, for an advanced price, to the Citizens of London; whereas now the roads are in a way to be made everywhere passable the City will be served with Mutton as cheap in the Winter as in the Summer, and the profit of the advance will be to the County Graziers, who are the original breeders and take all the Pains. This is evidenc'd to a Demonstration in the Counties where the Roads are already repaired, from whence they bring their fat Cattle, and particularly their Mutton, in Droves, from Sixty, Seventy or Eighty Miles without fatiguing, harassing or sinking the Flesh of the Creatures, even in the depth of the Winter."*

Some of the larger turnpike trusts from 1750 onwards appointed road engineers, with the result that numerous schemes of road-making, many of them extremely fantastic and impracticable, were tried; and it is declared that at this period upwards of a score of different types of road designs could be seen within a day's journey of the Metropolis. The generally accepted method of making a new road was first to lay a number of large stones, and to heap on these a number of smaller stones, until the surface of the road became semicircular in section. Convexity was so pronounced that vehicles had to keep to the surface in the middle of the road, as, especially in wet weather, the sides became very dangerous. The main object of this form of construction was to secure good drainage. In Postlethwaite's Dictionary it is stated that "the chief and almost the only cause of the deepness and foulness of the roads is occasioned by the standing water, which for want of due care to draw it off by scouring and opening ditches and draining, and other water courses, and clearing of passages soaks into the earth and softens it to such a degree that it cannot bear the weight of horses and carriages." It is easy to imagine that as carriages passed over these roads, ruts would gradually be formed, and the services of the road repairer would soon be required. The work of the road repairer of this period is referred to by Arthur Young, in describing the road to Wigan: "The only mending it receives is the tumbling in some loose stones, which serve no

* Defoe, *op. cit.*, II. 368.

other purpose but jolt a carriage in the most undesirable manner."

The rough empiricism of the road engineers of the Turnpike Trusts had to give place to more scientific methods of road-making by men who had made a close study of the subject. In response to public demands for improved roads, various House of Commons Committees were appointed to deal with the subject. Arising out of the recommendations of these Committees, systematic work on the roads was inaugurated, and this brought to light the work of John Metcalf, the blind road-maker of Knaresborough; provided opportunity to Thomas Telford, the stonemason, to carry into effect his carefully-thought-out designs for improved roads; and prepared the way for John Loudon Macadam, the Scottish inventor, to render signal service to the country in improving its internal communications, which culminated in his being appointed General Surveyor of Roads to the Government.

The first of the three great English road engineers was John Metcalf, who was born in Knaresborough in 1717. Metcalf struggled through life with the disability of blindness, which was the result of an attack of small-pox at the age of six. Despite this physical defect, the youth of Metcalf is a history of keen interest and shrewd activity, and his life-history is a record of adventure no less than of valuable achievement. He developed to a very marked degree the sense of direction, and though unaided by sight, so learnt the direction of roads and pathways that on more than one occasion he acted as a guide to travellers who had lost their way. After acting in various capacities as musician, soldier, fish-dealer, horse-dealer, and waggoner, Metcalf in 1765 entered upon the serious occupation of his life. In that year an Act was passed providing for the construction of a turnpike road between Harrogate and Boroughbridge, and the surveyor undertaking the work engaged Metcalf as road engineer for a length of 3 miles. He undertook the building of this first piece of road with most satisfactory results, and thus obtained his first experience in his newly acquired art. His next undertaking was a portion of the road between Harrogate and Knaresborough. Whilst surveying the ground over which the road was to be con-

structed he realized the change in its character at a certain part, and arranged for light excavations to be made, with the result that remains of an old Roman road were discovered beneath. He used part of the material thus found for the construction of the new road. A new difficulty was encountered in a large bog which stood in the path of the proposed road, but Metcalf devised a plan for carrying the road over this part rather than circling round its edge. The method adopted was to bind together small bundles of furze and ling, and place them in the direction of the proposed road across the bog. Then other bundles at right-angles to the direction of the first were placed as a second layer, followed by a layer of gravel placed over the whole. The operation was repeated a second time, and finally the road metals were placed on the top, resulting in a perfectly solid road which literally floated on the bog. It may be anticipated here that this was precisely the method adopted by George Stevenson in constructing the railway from Liverpool to Manchester which crossed Chat Moss. In all, Metcalf laid 180 miles of English roads in the counties of Lancashire, Yorkshire, Cheshire, and Derbyshire, the total value of his contracts amounting to £65,000. It was not until after his seventieth year that Metcalf ceased road-making, after which he devoted the remainder of his life, which ended in his ninety-third year, to writing his life-history.

The evidence which Telford gave before the Select Committees of the House of Commons in 1819 indicates his opinion of the roads of England and Scotland at that period. "They are in general, very defective both as to their direction and inclination; they are frequently carried over hills, which might be avoided by passing along the adjoining valleys . . . there has been no attention paid to constructing good and solid foundations; the metals, where consisting of gravel or stones, have seldom been sufficiently selected and arranged, and they lie so promiscuously upon the road as to render it inconvenient to travel upon them. . . . The shape of the roads, or cross-section of the surface is frequently hollow in the middle; the sides encumbered with great banks of road dirt, which have accumulated in some places to the height of 6, 7, or 8 feet; these prevent the water from flowing into the side drains;

they also throw considerable shade upon the road, and are gross and unpardonable nuisances. The metals, instead of being clean of the mud and soil with which they are mixed in their native state, are laid promiscuously upon the road." Telford attached great importance to the provision of adequate drainage. While giving a convex shape to the road, he employed the minimum curvature essential to secure top drainage and adequate distribution of internal pressure, and discontinued the somewhat grotesque curvatures which his predecessors had adopted. Throughout his system of road construction he endeavoured to avoid steep gradients, and was consequently often faced with the necessity of cutting through a hill-side.

It is convenient at this stage to review the social effects of Telford's work in the new construction of roads on the life and habits of the Scotch people. These effects may be most completely summarized in the words of the engineer himself: "In these works, and in the Caledonian Canal, about three thousand two hundred men have been annually employed. At first, they could scarcely work at all: they were totally unacquainted with labour; they could not use the tools. They have since become excellent labourers, and of the above number we consider that about one-fourth left us annually, taught to work. These undertakings may, indeed, be regarded in the light of a working academy, from which eight hundred men have annually gone forth improved workmen. They have either returned to their native districts with the advantage of having used the most perfect sort of tools and utensils (which alone cannot be estimated at less than ten per cent. on any sort of labour), or they have been usefully distributed through the other parts of the country. Since these roads were made accessible, wheelwrights and cartwrights have been established; the plough has been introduced, and improved tools and utensils are generally used. The plough was not previously employed; in the interior and mountainous parts they used crooked sticks, with iron on them, drawn or pushed along. The moral habits of the great masses of the working classes are changed; they see that they may depend on their own exertions for support; this goes on silently, and is scarcely perceived until apparent by the results. I consider these improvements among

the greatest blessings ever conferred on any country. About two hundred thousand pounds has been granted in fifteen years. It has been the means of advancing the country at least a century."*

John Loudon Macadam was born in Ayr in 1756, and even while at school constructed a model road section. At the age of fourteen he went to New York, and entered the service of a merchant uncle, returning to Scotland in 1783, with a small fortune as the result of thirteen years' successful business. He purchased in Ayrshire the estate of Sanchrie, where at his own expense he undertook numerous experiments in road-making. This had always been his hobby, but it now became his one absorbing interest in life. He became a propagandist in the cause of road-making, particularly of the improvement of existing roads. His general conclusion was that roads should be made of small broken stones, and he differed from Telford in that he regarded a firm foundation for the stone as of almost negligible importance provided the subsoil was kept dry by drainage. In 1815 he was appointed Surveyor-General for the Bristol roads, in which capacity he had ample opportunity for giving practical effect to his theories of road-making. He made two important contributions to the then sparse literature of road engineering: the first, written in 1817, was *A Practical Essay on the Scientific Repair and Preservation of Roads;* and the second in 1820, *The Present State of Road Making.* He displayed indomitable energy and zeal in advocating his system of road-making, and in the course of his labours travelled over 30,000 miles of road. He undertook the major portion of this work whilst serving in the capacity of Surveyor-General of Roads, which appointment he received in 1827.

Roads constructed according to the principles that he laid down have since his day been known as "Macadamized." Macadam prophetically declared that "a road ought to be considered as an artificial flooring, forming a strong smooth solid surface which should be at once capable of carrying great weights, and over which carriages may pass without meeting any impediment." However, road administrators down to the

* Smiles, *Lives of the Engineers,* "Telford" (ed. 1904), 251-252.

last decade of the nineteenth century were content with a more or less rough or irregular, or a more or less yielding or gravel surface, formed of imperfectly consolidated broken stones, in which the horse's hoof could find alike, in wet weather and dry, in summer heat and winter's frost, a firm foothold. The new County Councils, finding themselves from their establishment in 1888 fully responsible for the main roads, adopted from the outset a higher standard of efficiency in road administration than had before usually prevailed. We see, in fact, the cost rapidly increasing long before motor-cars began to appear on the roads. Thus, in the twelve years between 1890 and 1902, when the traffic was still almost wholly made up of horse-drawn vehicles and pedal bicycles, the total expenditure on main roads in rural districts was nearly doubled, the mileage being greatly increased and the annual cost per mile rising from £43 to £65. There was, in fact, between 1888 and 1902 a great amount of neglect to be made good as well as an increase in wear and tear to be provided for. A large proportion of the roads were found to have "no bottom," and needed entire reconstruction. These improvements, rendered still more imperative by the rapid transformation of the traffic since 1902, steadily continued, and nowadays there are excellent and well-maintained roads throughout the whole of the country. Perhaps the most important advance has been that of sinking to render the surface both smooth and watertight, and it is now possible to obtain practically dustless roads by spraying with preparations of tar.

Roads in which steep gradients are to be avoided must necessarily often pass through hill-sides, and across steep valleys and running streams. The road-maker must, therefore, combine with his art that of bridge-building, and we have already noted in passing something of the work which Telford carried out as a bridge engineer. Bridges in England had an early origin. The medieval bridges, both on the Continent of Europe and in this country, were constructed under ecclesiastical auspices, and were usually dedicated to a patron saint. Apart from the Egyptian-looking cyclopean bridges of Dartmoor, one of which, reputed to have lasted 2,000 years, crossed the East Dart at Tavistock, and consisted of huge slabs 16 feet by

16 feet resting on three rude piers, one of the oldest English bridges is the triangular bridge at Croyland,* near Peterborough. It was probably built by the Abbots of Croyland Abbey, and is referred to in a Charter of the year 943.

The first road-bridge built of stone, as to which definite records are extant, crosses the River Lea at Bow near Stratford, and was constructed by order of Matilda, wife of Henry I. The Queen had been in peril in crossing the ford which had previously existed, with the result that she directed two bridges to be built, one at Bow, and one at Charmslea. In order to withstand the force of the stream it was curved up-stream, and constitutes the first curved bridge in the country. Queen Matilda also endowed the Bow Bridge by purchasing local properties and presenting these to the Abbess of Barking on condition that she and her successors should keep the bridge in proper repair. In later times a toll was levied to maintain the bridge in repair, and in King John's time we find that carts carrying corn, wood, or coal had to pay 1d. each. Jews were especially penalized in this respect, and even at Kew, Jewish pedestrians were required to pay ½d. each, and equestrians 1d. each, to cross the bridge. Another important Norman bridge is the Devil's Bridge near Aberystwyth. Various theories attach to the building of this bridge, the most interesting being the popular legend† which attributes its origin to the Devil, who is also in legend held responsible for other bridges of the same name. Later (1835-39) this bridge was replaced by a

* "The famous bridge at Croyland is among the greatest curiosities in Britain. It is of triangular form, rising from three segments of a circle, and meeting at a point at top. It seems to have been built under the direction of the abbots, rather to excite the admiration and furnish a pretence for granting indulgence and collecting money, than for any real use; for though it stands in a bog, and must have cost a vast sum, yet it is so steep in its ascent and descent that neither carriages nor horsemen can get over it."—"History and Antiquities of Croyland Abbey," in *Bibliotheca Topographica Britannica*, No. 11. Quoted by Smiles, *op. cit.*

† The legend is contained in the following lines, taken from the *Gossiping Guide to Wales :*

"Old Megan Llandnnach
Of Pont-y-Mynach
Had lost her only cow;
Across the Ravine
The cow was seen,
But to reach it she could not tell how.

66-foot span stone arch, and finally, in 1904, by a steel girder bridge in order to improve the roadway over the water.

The existence of bridge-chapels has already been noted. Smiles refers to them as follows: "The chapel was invariably dedicated to some patron saint. That on old London Bridge was dedicated to St. Thomas, on Bow Bridge to St. Catherine, and others were dedicated to St. Nicolas, the patron saint of sailors. The chapels were exceedingly picturesque objects, and were often highly decorated. They were erected over one of the piers, about the centre of the bridge, elongated for the purpose; and a brother stood at the door to receive the offerings of the passers-by towards the repairs of the bridge and the support of the services of the chantry. There was a chapel on a bridge in Droitwich, Worcestershire, through which the high turnpike road passed until a few years ago; and the congregation sitting on the one side of the King's way heard the preacher from the pulpit on the other. Nearly all these old bridge-chapels have disappeared, but a beautiful specimen has happily been preserved in the chantry on Wakefield Bridge."

The Devil that day
Chanced to wander that way;
Says he, 'Megan, what's the matter ?'
'I'm ruined,' says she,
'The Cow's lost to me,'
And she set up a dolorous clatter.
Says the Devil, 'A bridge
I'll raise from the ridge,
And the two rocks together will join,
And recover your loss.
But the first thing that shall cross
Must ever and ever be mine.'
Old Megan, contented,
Then quickly consented;
Satan hoped to have made her his prey.
So under her nose
The high arch rose;
Says the Devil, 'Now trudge it away.'
In her pocket she fumbled,
A crust out she tumbled,
And called her little black cur.
The crust over she threw,
The cur after it flew;
Says she, 'The dog's yours, crafty Sir.'
The Devil looked queer,
And scratched his right ear,
Then sprang from the edge of the Ravine;
Says he, 'A fine hit, the biter is bit,
For the Mangy cur isn't worth having.'"

The earliest bridge across the Thames was a wooden structure. It is referred to in the Laws of Ethelred (tenth century), in which are enumerated the tolls of vessels which proceed to Billingsgate, *ad pontem*. Reference is also made by William of Malmesbury to the destruction of the bridge in 994, during one of the encounters with the Danes who sailed up the Thames; it was then rebuilt, but only to be swept away in 1091 by a flood. It was again reconstructed in 1097, but after a lapse of fifty years, it was ravaged by fire, and again fell. It was finally resolved to build a bridge of stone upon a site a little to the west of that on which the earlier bridges had been built. The stone bridge was commenced in 1176 by the chaplain of St. Mary's, Colechurch, named Peter. It occupied thirty-three years in the building, being finished in 1209. "The bridge, when finished, was a remarkable and curious work. That it possessed the elements of stability and strength was sufficiently proved by the fact that upon it the traffic of London was safely borne across the river for more than six hundred years. But it was an unsightly mass of masonry, so far as the bridge was concerned; although the overhanging buildings extending along both sides of the roadway, the chapel on the centre pier, and the adjoining drawbridge, served to give it an exceedingly picturesque appearance. One of the houses adjoining the drawbridge was dignified with the name of Nonsuch House; it was said to have been constructed in Holland and brought over in pieces, when it was set up without mortar or iron, being held together solely by wooden pegs."* Until the middle of the eighteenth century the old London Bridge remained the only road across the Thames at London. Shortly after its construction it was ravaged by a fire that destroyed the numerous wooden houses that had been constructed thereon. The houses were afterwards rebuilt, as their rental constituted an important source of income for the maintenance of the bridge. Its upkeep was costly, for it needed almost continuous attention. A second bridge, Westminster Bridge, was constructed during the years 1738-1750 by the French engineer Labelye, when old London Bridge had become quite inadequate to meet the needs of the city.

* Smiles, *Lives of the Engineers*, "Smeaton and Rennie," 74.

One of the greatest difficulties of the early bridge-builders was the construction of suitable foundations. "A common practice was to sink baskets of small dimensions, full of stones, in the bed of the river, and on these, when raised above water, the foundations were laid. But where the bottom was composed of loose, shifting material, such as sand, it will be obvious that a firm basis could scarcely be secured by such a method. The plan adopted by Labelye, though considered an improvement at the time, was even inferior to the method employed by Peter of Colechurch in founding the piers of old London Bridge in the thirteenth century. For though the latter construction was clumsy, it stood more than six hundred years, whilst Westminster Bridge had not been erected a century before it exhibited signs of giving way; and it is already destroyed. Labelye's method of founding his piers was as follows: He had a sufficient number of large caissons, or water-tight chests, prepared on shore, of such form as to fit close alongside of each other. They were then floated on rafts over the spots destined for the piers where they were permanently sunk. The top of each caisson, when sunk, being above high-water mark, the masonry was commenced within it, and carried up to a level with the stream, when the timber sides were removed and the pier was left resting firmly on the bottom grating. The foundations were then protected by sheet-piling —that is, by a row of timbers driven firmly side by side into the earth all round the piers."* "With the growth of city traffic, the need for a third bridge across the Thames became urgent, and an Act empowering the construction of a bridge at Blackfriars was passed and work commenced in 1760 and finished in 1769. Mr. Robert Mylne, the architect and engineer, introduced in this bridge the elliptical arch which had not previously been used in England."

After the Westminster Bridge was completed, attention was turned to the obvious defects of the old London Bridge. Acting on the advice of both Labelyė and Sir Christopher Wren, the Council decided to remove the middle pier and replace the adjoining two locks by one new arch. The removal of these impediments caused the river to wash the foundations of the

* *Ibid.*, 82.

remaining piers with a strong "scour" which placed the bridge in danger. In their consternation the Council requisitioned the help of Smeaton, who had made himself famous as the engineer of the Eddystone Lighthouse. Smeaton advised protecting the piers by throwing around them large blocks of stone, recommending for the purpose the stone of the city gates which had been recently demolished; his suggestion was carried into effect, and the life of the bridge was extended by half a century, when it was replaced by the new London Bridge.

Though Smeaton was associated with the construction of a number of small bridges, his reputation as a bridge-builder was earned largely as a result of the work he undertook in bridging the Tay, at Perth. The frequent floods on the Tay necessitated special precaution in the construction of the pier foundations, and the method adopted by Smeaton was to drive into the bed of the river piles to form an enclosure, the outside of which was surrounded by earth thrown into the river to render the enclosed space watertight. Pumping operations were then carried on in the enclosure, the inside of which was thus made dry. Foundation digging was then commenced and a solid foundation for the piers thus secured. The bridge when finished was 900 feet in length, and included seven principal arches. It was opened for service in 1772, and found of great use. Smeaton designed two other Scotch bridges of note, the Coldstream Bridge across the Tweed, and the Banff Bridge across the River Deveron, near the town of Banff. The characteristic feature of these, as of all his bridges, was the introduction of circular perforations in the spandrels of the arches, which considerably reduced the weight of the structure and thus decreased the stress of the pier foundations. His one unsuccessful bridge was across the Tyne at Hexham, which he designed in 1777, and had carried out under the supervision of Mr. Pickernell. The foundations were insecurely laid, and a severe storm in the spring of 1782, with a heavy river surge, demolished the bridge. Writing to his resident engineer, Mr. Pickernell, Smeaton said: "All our honours are now in the dust! It cannot now be said that in the course of thirty years' practice, and engaged in some of the most difficult enter-

prises, not one of Smeaton's works has failed! Hexham Bridge is a melancholy instance to the contrary." Later he added: "The news came to me like a thunderbolt, as it was a stroke I least expected, and even yet I can scarcely form a practical belief as to its reality. There is, however, one consolation that attends this great misfortune, and that is, that I cannot see that anybody is really to blame, or that anybody is blamed; as we all did our best, according to what appeared; and all the experience I have gained is, not to attempt to build a bridge upon a gravel bottom in a river, subject to such violent rapidity."* We shall find that the real problem of proper foundation construction in rivers was not solved until the time of Rennie; that the engineer who laid a foundation of "gravel and even mould earth mixed together" at an insufficient depth only had the foundation washed away by the increased scour caused by the reduced width of flow upon the introduction of piers in the river.

John Rennie was born in East Lothian on June 7, 1761, the youngest of five children. He was only five years of age when his father died; the boy's early education was undertaken at the local parish school. During his school days he displayed great keenness in mechanical pursuits, and became closely attached to Andrew Meikle, a millwright, whose shop he had to pass each day on his way to school. Upon completing his school training at the age of twelve, he was apprenticed to Andrew Meikle, and engaged in practical work for two years, acquiring skill in the millwright's art. His friends then resolved that young Rennie should proceed to the Dunbar High School, which enjoyed a special reputation in Scotland. Here he was fortunate in coming under the personal notice of Mr. Gibson, the mathematical master, who took a particular interest in developing the mathematical talents of the embryo engineer. After two years of intensive study, chiefly of mathematics and science, Rennie returned to his native village of Phantassie in East Lothian, in order to pursue his favourite work with Andrew Meikle. The major portion of his time was spent in advancing his own education, especially in mathematics, mechanics, and applied science, and he visited the millwright's

* Quoted by Smiles, *op. cit.*, 179.

workshop at intermittent periods, assisting in the development of new inventions and designs in which his master was interested. At the same time he began to undertake mill construction on his own account, and during his nineteenth year he executed his first contract in fitting out new mills at Invergowrie, near Dundee. His aims, however, were beyond those either of a millwright or a factory builder. His initial groundwork at the Dunbar High School, combined with his own subsequent home studies, qualified him for admission to the University of Edinburgh, which he entered at the end of 1780, maintaining himself during his college course by his labours during the long vacation. Upon the completion of his three-year college course, he resolved on taking a tour through the industrial centres of England, in order to become familiar with English engineering practice. While in Lancashire he inspected the bridge across the Lune, which had been constructed by Mr. Harrison, the Bridgewater Canal at Manchester, and the dock construction then in progress at Liverpool. At Birmingham he visited the engineering works of Boulton and Watt at Soho, and shortly afterwards received an invitation to assist the two pioneer engineers in the development of their work. Watt's invitation found Rennie in the midst of constructing his first bridge across the Water of Leith, about 2 miles west of Edinburgh: a simple bridge of three arches and two piers, and the first on the Glasgow and Edinburgh turnpike road. Rennie accepted this invitation, and while in their employ was responsible for the construction and installation of two double-acting engines, each of 50 horse-power, at the Albion Mills in London.

We are concerned here with the work of Rennie as a bridge-builder only, although as a builder of canals, docks, and lighthouses he was equally famous. Mention has already been made of his first bridge outside Edinburgh. He also constructed two other important Scotch bridges—namely, the Kelso Bridge across the Tweed, opened in 1803, and the Musselburgh Bridge across the Esk. These two bridges were similar in construction, each consisting of five semi-elliptical arches, and embodying a somewhat new feature of that period, in so far as the roadway across the bridge was level, and not inclined on either side, reaching an apex in the middle, as was characteristic

of the majority of bridges at that period. In contradistinction to the method of Smeaton, Rennie laid the foundations for his piers very deep and firm, and upon a solid rock underlying the river-bed. This was achieved by the same general method as had been adopted by Smeaton—namely, by the use of the coffer-dam, but he dug deeper in the river-bed for his foundations than had been usual in earlier practice.

Rennie's first English bridge was constructed at Boston, in Lincolnshire, but his reputation as a builder of bridges was completely established upon the execution of the Waterloo Bridge, London. At the beginning of the nineteenth century the Thames at London was spanned by the old London Bridge, the Westminster Bridge, and the Blackfriars Bridge. The Metropolis was rapidly growing, and the necessity for more adequate transport facilities between the north and south banks of the river was becoming increasingly urgent. A bridge was proposed to cross the river at Lambeth, to enter the north bank at the Strand, near Somerset House, and in 1809 a company was floated in order to carry out the work. The original plans submitted by George Dodds were discarded in favour of a more reliable scheme propounded by Rennie. Rennie's design ensured that the roadway of the bridge should be as nearly on a level with the Strand as possible, and there was only 2 feet difference between the summit of the bridge and the road level. Two designs were submitted, one of seven arches and the other of nine, and the latter was finally adopted by the committee. The bridge was opened on June 18, 1817. It is of interest to observe that on this occasion Rennie declined a proffered knighthood, choosing rather the solid monument of his skill as his sufficient honour.

Rennie's next work was an iron bridge across the Thames, the famous Southwark Bridge, and owing to the necessity for reducing the waterway as little as possible at this narrow part of the river, he designed a bridge of three arches, thus requiring only two piers in the river. The cast-iron arches represented bold practice for that period. The centre arch was 240 feet long, being 4 feet larger than the largest bridge that had been built up to that time, and the side arches were each 210 feet in length. The massive proportions of the arches

have been adversely commented upon and regarded as a waste of material by certain critics, who consider that much lighter members would have carried the greatest load likely to be imposed. But the art of casting was much less perfect in those days, and Rennie was probably right in running no risks. There are 3,620 tons of cast iron and 112 tons of wrought iron in the bridge. Speaking of Southwark Bridge, Robert Stephenson later said: "As an example of arch construction, it stands confessedly unrivalled as regards its colossal proportions, its architectural effect, and the general simplicity and massive character of its details."*

The characteristics of the old London Bridge have been noted earlier, together with its expensive upkeep. During the early part of the nineteenth century it cost the Corporation £3,500 a year to maintain the bridge in a tolerably good condition. It was felt that some action in respect to the bridge should be taken, and Rennie was asked to report. He presented his report on March 12, 1821, and in it adduced many good reasons for the building of an entirely new bridge. This was agreed to, and Rennie prepared the plans, but died before he could carry them into effect. The actual work of bridge construction was undertaken by his son, who afterwards became Sir John Rennie. The work was commenced in 1824 and completed in 1831. It provides one of the finest examples of a masonry arch extant. When completed, the bridge had a total width of 56 feet, but with increasing traffic the necessity for greater width became pronounced. A scheme for widening it was adopted in 1900, and was carried out in 1902, so that to-day the bridge has a total width of 65 feet, comprising a 35-foot roadway and two footways, each 15 feet wide.

As a result of the increase in traffic in the coal, iron, brick and pottery trades near Shrewsbury towards the end of the eighteenth century, some more permanent method of crossing the Severn than the use of ferries became necessary. It was across this river that the first iron bridge built in England was constructed. It was cast under the supervision of Mr. Abraham Darby, at the Coalbrookdale Iron Works, and consisted of one semicircular arch of 100 feet span, each rim being cast in two

* Quoted by Smiles, *op. cit.*, 333, 334.

pieces. The result of the deviation of the trade route across this bridge was the growth of a small town known as Ironbridge. As Robert Stephenson wrote: "If we consider that the manipulation of cast iron was then completely in its infancy, a bridge of such dimensions is doubtless a bold as well as an original undertaking, and the efficiency of the details is worthy of the boldness of the conception."*

The next projector of iron bridges was destined to earn distinction as a social reformer rather than as an engineer. After a varied career, Tom Paine, the son of a Quaker of Thetford, emigrated to America and became involved in a project to construct an iron bridge over the River Schuylkill. He returned to England to have his proposed arch of 400 feet span cast at Rotherham. The castings of this were exhibited in London, where they attracted considerable attention, but the outbreak of the French Revolution interested Paine more than the peaceful art of bridge-building, and he left his bridge in order to respond to other calls. The manufacturers reclaimed the castings, and the materials were afterwards used in the construction of a bridge projected by Roland Burdon, of Castle Eden, over the weir at Sunderland in 1796. "We should probably make a fair division of the honour connected with this unique bridge, by conceding to Burdon all that belongs to a careful elaboration and improvement upon the designs of another, to the boldness of taking upon himself the great responsibility of applying this idea at once on so magnificent a scale, and to his liberality and public spirit in furnishing the requisite funds (to the amount of £22,000); but we must not deny to Paine the credit of conceiving the construction of iron bridges of far larger span than had been made before his time, or of the important examples, both as models and large constructions, which he caused to be made and publicly exhibited. In whatever shares the merit of this great work may be apportioned, it must be admitted to be one of the earliest and greatest triumphs of the art of bridge construction."†

In the same year (1796) Telford built his first iron bridge

* Smiles, *Lives of the Engineers* (1904), "Telford," 210.

† Report by Mr. Phipps to Robert Stephenson. Quoted by Smiles, *op. cit.*

across the Severn at Buildwas, near Shrewsbury, and enlisted the aid of the Coalbrookdale ironmasters in preparing the castings. Telford's experience in iron bridge building increased. During the time he held the office of Surveyor to the County of Salop he erected forty-two road bridges, five of which were constructed of iron. As a result of the number of bridges he constructed, his friend Southey styled him "Pontifex Maximus." His boldest project was made in 1801 when, in the discussion of plans for the rebuilding of the old London Bridge, he proposed a single cast iron arch of 600-feet span, which should be the segment of a circle of 450 feet in diameter. The next important bridges were constructed on the Holyhead road for the purpose of facilitating communication with Ireland. Rennie, in 1801, had reported to the Secretary of State for Ireland on the condition of the North Wales road to Holyhead, and in his recommendations for their improvement had proposed the construction of iron bridges across the Conway and over the Menai Straits. His designs were bold advances on the iron bridge practice of that period, and his proposals were regarded as too daring to be practicable or safe; they were therefore not adopted. Nothing was done until 1815, when a Board of Parliamentary Commissioners was appointed, and under their superintendence the Shrewsbury to Holyhead road was constructed. It was some years, however, before the road was improved to the point of the provision of bridges across the Conway and Menai Straits. In the meanwhile Telford prepared a design for a suspension bridge across the Mersey at Runcorn, and in proposing the suspension design, directed public attention to this type of construction. He showed that this design had frequently been employed in India and America as a convenient method of bridging wide rivers, and even in this country a rude bridge had long been in use at Middleton on the Tees, and consisted of two chains stretched across the river, upon which a footway of boards was laid. This bridge was used by colliers in going to and from their work.

Telford was now consulted respecting the possibility of constructing a bridge on the suspension principle across the Menai Straits, and he submitted his scheme in 1818. His plan

was to keep the roadway at least 100 feet above high-water mark so as not to interfere with the navigable waterway below. He proposed a 550-foot span between the centres of the supporting pyramids, and the height of the latter above the roadway was fixed at 53 feet. Sixteen main chains were to be used, each consisting of thirty-six bars of ½-inch squared iron, welded and braced throughout their length. The ends of the chains were to be secured in a mass of masonry built over stone arches situated between the supporting pier and the adjoining shore. As in the Runcorn design, the roadway was to consist of a 12-foot carriage way on either side of a centre 4-foot footway. Telford's plan was supported by eminent engineers of the day, including Rennie, and the necessary Act empowering the construction of the bridge was passed in 1819, after which Telford immediately took in hand the work. The building operations were begun early in 1820, and the arches, three on the Carnarvon side and four on the Anglesey side, were first constructed. Great care was exercised in the selection and testing of all the wrought iron, and Telford undertook numerous experiments and advised a large number of tests to ensure that only the best material was used. The contract for the iron was let to Mr. Hazeldean, of Shrewsbury, in 1820, and only best Shropshire iron drawn at Upton Forge was used. After conducting many experiments with a view to calculating the power that would be required to lift the main suspension chains into their proper positions, Telford decided to build a central portion of each chain upon a raft 450 feet long and 60 feet wide, then float this to the side of the bridge and lift it into position by capstans. The success which attended the placing of the first chain according to this method was very pronounced, and the suspension of the remaining foundation chains was merely a matter of time, and was completed on July 9, 1825. The following month the road platform was commenced, and the work finally completed and opened for public traffic on Monday, January 30, 1826, when the London to Holyhead mail coach passed over. While the Menai Bridge was in course of construction, a bridge over the Conway at Conway Castle was also being constructed, in order to form part of the Holyhead road and avoid the necessity of trans-

ferring into ferry boats in order to cross the river. The general design and methods of construction were similar to those already described in connection with the Menai Bridge.

The Stephensons in their pioneer work of railway construction were necessarily interested in bridge-building in order to provide suitable roadways for their railways. The fact that the Newcastle and Berwick railway necessitated 110 bridges gives some indication of the experience which the Stephensons obtained in this branch of work. The most important bridge included in this line is the Royal Border Bridge at Berwick-on-Tweed, which was designed by Robert Stephenson, and consists of twenty-eight semicircular arches. The foundations of the piers were laid by means of coffer-dams, and it is of interest to observe that Nasmyth's steam-hammer was extensively used for driving in the piles. The High Level Bridge at Newcastle was also necessitated by the East Coast Railway route, and an Act for the construction of the bridge was passed in 1845. The greatest difficulty Stephenson experienced in constructing his High Level Bridge at Newcastle was in securing a solid foundation for the piers. The piles to be driven in were of too great dimensions to be managed by hand, and for the first time in bridge-building Nasmyth's steam hammer was used for pile-driving. The steam engine and hammer apparatus were supported on a temporary staging, and on October 6, 1846, the first pile was driven to a depth of 34 feet in two minutes. Two hammers, each of 30 cwt., were kept in continual action, and made from sixty to seventy strokes a minute, and effectively demonstrated that pile-driving, formerly a costly and tedious processs, had now become rapid, easy, and economical.

"The rapid extension of railways had given an extraordinary stimulus to the art of bridge-building; the number of such structures erected in Great Britain alone, since 1830, having been above 25,000, or more than all that had before existed in the country. Instead of the erection of a single large bridge constituting, as formerly, an epoch in engineering, hundreds of extensive bridges of novel design were simultaneously constructed. The necessity which existed for carrying rigid roads capable of bearing heavy railway trains at high speeds, over

extensive gaps free of support, rendered it obvious that the methods which had up to that time been employed for bridging space were altogether insufficient. The railway engineer could not, like the ordinary road engineer, divert his road and make choice of the best point for crossing a river or a valley. He must take such ground as lay in the line of his railway, be it bog, or mud, or shifting sand. Navigable rivers and crowded thoroughfares had to be crossed without interruption to the existing traffic, sometimes by bridges at right angles to the river or road, sometimes by arches more or less oblique. In many cases great difficulty arose from the limited nature of the headway; but, as the level of the original road must generally be preserved, and that of the railway was in a measure fixed, it was necessary to modify the form and structure of the bridge in almost every case, in order to comply with the public requirements. Novel conditions were met by fresh inventions, and difficulties of the most unusual character were one after another successfully surmounted. In executing these extraordinary works, iron had been throughout the sheet-anchor of the engineer. In its cast or wrought forms, it offered a valuable resource where rapidity of execution, great strength, and cheapness of construction in the first instance, were matters of prime importance; and by its skilful use, the railway architect was enabled to achieve results which thirty years before would scarcely have been thought possible."*

In 1838 George Stephenson was invited to survey the Chester to Holyhead Railway, which had become necessary owing to the growth of the Irish trade. Stephenson's original plan for the Menai Bridge was the construction of two cast-iron arches, each of 350 feet span. This design the Admiralty rejected, as under no circumstances was the navigation of the Straits to be interfered with, and even the erection of scaffolding from below to support the bridge during construction was not to be allowed. A suspension design was also dismissed, as it was considered not sufficiently strong for a railway bridge. Finally, Stephenson decided on the adoption of a large wrought-iron girder built in the form of a tube. The metal is so distributed that the tube acts as a beam, with the bulk of the metal in

* Smiles, *Lives of the Engineers*, "Robert Stephenson," 376-378.

the top and bottom members. The bridge consists of two separate tubes, mounted side by side on piers, each tube carrying a single railway track. The Conway railway bridge was of the same structure, and was built simultaneously with the one at Menai. It appeared doubtful whether the tubes of the Britannia Bridge, at Menai, would be strong enough by themselves to fulfil requirements, and as a precautionary step the masonry towers, appearing Egyptian in design, were built sufficiently high to admit of the tubular beams being reinforced, if necessary, by attachment to suspension chains supported by the towers.

Stephenson's own account of the placing in position of the first tube is full of interest, and shows the extreme caution taken in carrying out his design. "In a work of such novelty and magnitude you may readily imagine I saw that every possible contingency should be provided for. Where one chain or rope was required, I provided two. I was not satisfied with 'enough': I must have absolute security as far as that was possible. I knew the consequences of failure would be most disastrous to the Company, and that the wisest economy was to provide for all contingencies at whatever cost. When the first tube at the Britannia had been successfully floated between the piers, ready for being raised, my young engineers were very much elated, and when the hoisting apparatus had been fixed, they wrote to me, saying: 'We are now all ready for raising here: we could do it in a day, or in two at the most.' But my reply was: 'No; you must only raise the tube inch by inch, and you must build up under it as you rise. Every inch must be made good. Nothing must be left to chance or good luck.' And fortunate it was that I insisted upon this cautious course being pursued; for one day, while the hydraulic presses were at work, the bottom of one of them burst clean away. The crosshead and the chains, weighing more than 50 tons, descended with a fearful crash upon the press and the tube itself fell down upon the packing beneath. Though the fall of the tube was not more than nine inches, it crushed solid castings, weighing tons, as if they had been nuts. The tube itself was slightly strained and deflected, though it still remained sufficiently serviceable. But it was a tremendous test to which

it was put, for a weight of upwards of 5,000 tons falling even a few inches must be admitted to be a very serious matter. That it stood so well was extraordinary. Clark immediately wrote me an account of the circumstances, in which he said: 'Thank God, you have been so obstinate. For if this accident had occurred without a bed for the end of the tube to fall on, the whole would now have been lying across the bottom of the Straits.' Five thousand pounds extra expense was caused by this accident, slight though it might seem. But careful provision was made against future failure; and a new and improved cylinder was provided: and the work was very soon advancing satisfactorily towards completion."* After the placing of the first tubes, the rest was straightforward. On March 5, the work was completed, and Stephenson with a great concourse of people crossed the bridge in a train drawn by three locomotives.

Latterly reinforced concrete has been found to be a suitable material for bridge construction. The first practical application of this material in this country was in 1854, when Wilkinson, a plasterer, took out a patent for reinforcing concrete floors. The pioneers of the new material are chiefly of foreign extraction, and to-day systems of ferro-concrete construction are known by the names of Coignet, Monier, Hennibique, Melan, and Considere. Probably the first reinforced concrete bridge constructed in the United Kingdom is that crossing the Sutton Canal at Hull, which is built on the Hennibique system. An important advantage of ferro-concrete over steel for bridge-building is the lower cost of construction. The following table illustrates the relative cost† of these two methods, and includes foundations, piers, abutments, approaches, footpaths, and machinery.

At the same time, however, certain disadvantages are inherent to the use of ferro-concrete, chief among which are the difficulty of making alterations to the bridge when completed, the limitation of the span, difficulty of erection, the greater weight of ferro-concrete bridges as compared with steel, and injurious effect of salt and brine on ferro-concrete causing the concrete round the reinforcements to crack, which,

* Smiles, *op. cit.*, 408.

† Pre-war prices.

unless quickly detected, will result in the failure of the structure.

Type of Bridge.	*Span (Feet).*	*Number of Spans.*	*Cost per Foot (Superficial).* £ s. d.
Ordinary concrete ..	30–50	Single	1 2 0
		Multiple	2 4 0
Reinforced concrete ..	50–100	Single	10s. to £1
		Multiple	1 2 0
Steel girder or lattice ..	50–100	Single	1 3 0
		Multiple	2 5 0
Steel suspension	50–100	Single	1 2 0
	100–200	Multiple	2 4 0

During recent years various new conditions have arisen that have exerted a pronounced influence on the development of bridge engineering. Development in ship-building has created the need for large span bridges that will give head room on the water, and opening and transport bridges have had to be designed to meet those cases in which it was impracticable to obtain the necessary head room of an ordinary span bridge. Railways have necessitated stronger bridges, and so quickly have railway loads increased that a large percentage of the earlier railway bridges have had to be replaced by stronger ones. The weight of a locomotive and tender has increased almost fourfold since 1860, and it is of interest to contrast the weight of a modern locomotive with that of the "Rocket," which weighed only 4¼ tons. Highway loads have also increased very considerably since the advent of traction engines, steam rollers, electric trams, etc. As an example of the loads for which a modern bridge is designed, those taken for the Kendby Bridge, across the River Trent, may be quoted. This bridge, opened in 1916, carries a double line of railway and a roadway about 16 feet wide, exclusive of footway. "On the railway portion of the structure the adopted loading consisted of a series of locomotives having a maximum axle load of 22 tons. On the roadway the floor system was designed to allow for the passage of two 40-ton trollies, each drawn by a 30-ton traction engine, in addition to which a superficial load

of 1 cwt. per square foot over the entire floor area, not covered by the running load, was allowed for." In addition, allowance for the dead weight of the structure itself, the impact effect of the moving loads, and wind pressure on the girders, etc., would be made.

Improvements in manufacturing processes, in the construction of tools and appliances, such as lifting gear, and in transportation methods generally, have had immeasurable effect on the development of bridge construction as on that of other branches of science. The use of compressed air has enabled foundations to be constructed in deep waters to carry the piers of bridges for spans that it would have been impracticable to have bridged otherwise—though it may be mentioned incidentally that compressed air was not used for those bridges which have the deepest foundations. The importance of the introduction and use of hydraulic and electrical machinery and appliances is also beyond estimation.

CHAPTER VI

THE AGE OF STEAM

As far back as the seventeenth century the first practical application of the elastic force of steam was proposed by the Marquis of Worcester in the *Century of Inventions*,* the original manuscript of which is now in the British Museum. The Marquis, during the troubled times of the Stuarts, was imprisoned in the Tower of London, and the story goes that seeing the lid of the pot in which his dinner was cooking suddenly rise, it occurred to him that the same force which had lifted the pot lid might also be used as a motive power. When he was released from the Tower he gave expression to this idea in the book referred to above. He describes the mechanism as " fire-water work," and although the description of this device is of a very vague character, it is quoted in full as follows: " An admirable and most forcible way to drive up water by fire, not by drawing or sucking it upwards, for that must be, as the philosopher calls it, *infra sphæram activitatis*, which is but at such a distance. But this way hath no bounder, if the vessels be strong enough; for I have taken a piece of whole cannon, whereof the end was burst, and filled it three-quarters full, stopping and screwing up the broken end, as also the touch hole, and making a constant fire under it; within 24 hours it burst and made a great crack; so that having found a way to make my vessels, so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water flow like a constant fountain stream, 40 feet high; one vessel of water rarefied by fire, driveth up 40 of cold water,

* The full title of the Marquis of Worcester's book is as follows: " A Century of the Names and Scantlings of such inventions as at present I can call to mind to have tried and perfected, which (my former Notes being lost) I have, at the instance of a Powerful Friend, endeavoured now, in the year 1655, to set these down in such a way as may sufficiently instruct me to put any of them in practice.—Artis & Natureo proles. London: Printed by J. Grismond, in the year 1663."

and a man that tends the work, is but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with cold water, and so successively the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim, between the necessity of turning the said cocks."*

On the basis of this description Dr. Robison† hastened to the conclusion that the steam engine was, beyond all doubt, the invention of the Marquis of Worcester. However, this is not a correct assumption, as there can be little question that the invention of the steam engine was the result of the efforts of many people; and it would be unfortunate to dissociate from these earlier efforts the name of De Caus, whose work on the Continent was of a monumental character. Solomon de Caus, who was born in Dieppe, vies with the Marquis of Worcester for the laurels of having first conceived the idea of the steam engine. In a work entitled *Les Raisons des Forces Mouvantes*, which bears a date of publication forty years earlier than the *Century of Inventions*, a complete description is given of the bombshell and tube described by the Marquis of Worcester. Not only was the latter thus anticipated in his main idea, but he was also not made of that clay which enabled him to pursue this idea to its logical conclusion. Walpole describes him in the following terms: "He appears in a very different light in his public character and in that of an author. In the former he was an active zealot; and in the latter, a fantastic mechanic; in both very credulous. . . . We find him taking oath upon oath to the Pope's nuncio, with promises of unlimited obedience both to his holiness and his delegate; and begging five hundred pounds of the Irish clergy to enable him to embark and fetch fifty thousand pounds; like an alchemist who begs a trifle of money for the secret of making gold." It is, therefore, not surprising that he allowed the ideas set forth in the *Century of Inventions* to lie dormant. There is also no evidence to show that Solomon de Caus constructed the apparatus he conceived.

* Quoted by Galloway in *History and Progress of the Steam Engine*, 9.

† John Robison, while a student at Glasgow College, became associated with Watt; afterwards he became Professor of Natural Philosophy at Edinburgh, and was editor of the *Encyclopædia Britannica*, to which he made many valuable contributions.

The next name associated with the development of the steam engine is that of Dionysius Papin,* by birth a Frenchman, who fled to England from his native country in 1681 to escape religious persecutions a few years before the Revocation of the Edict of Nantes. Papin became associated with the Royal Society in this country, and carried out extensive experiments relating to the application of steam power. All his experiments, however, were conducted by models, none of which were very successful from a practical point of view, owing largely to the fact that Papin was not a mechanic and was unable, therefore, to exercise that mechanical skill which later experimenters proved to be essential in the successful construction of the early steam engines. His experiments led him to the conclusion that a vacuum should be formed in a cylinder beneath a piston, when the atmospheric pressure operating on the other side of the piston would cause this depression. In 1688 he devised a method of obtaining a vacuum by displacing the air through the explosion of gunpowder. This method was abandoned two years later on account of its dangers, and at the same time he employed steam to raise the piston and afterwards, by the condensation of the steam, created a vacuum. In describing his apparatus, Papin wrote: "In a little water, changed into steam by means of fire, we can have an elastic power like air; but that it totally disappears when chilled, and changes into water, by which means he perceived that he could contrive a machine in such a manner that with a small fire he could be able, at a trifling expense, to have a perfect vacuum." After noticing the difficulty of making a vacuum by gunpowder, he observes: "Where there may not be the conveniency of a near river to run the aforesaid engine, I propose alternately touching a small surface of water into vapour by fire, applied to the bottom of the cylinder which contains it; which vapour

* Dionysius Papin, or as he is sometimes called, Denys Papin, was chiefly known in England through the design of a machine called a "digester," explained in a publication bearing the following title: "A new Digester or Engine for softening bones, containing the description of its make and use in these particulars, viz: Cookery, Voyages at Sea, Confectionary, Making of Drinks, Chymistry, and Dyeing. With an account of the price a good big engine will cost and of the profit it will afford. By Denys Papin, M.D., Fellow of the Royal Society, London. Printed for Henry Bonwicke at the Red Lyon on St. Paul's Churchyard, 1681."

forces up the block or piston in the cylinder to a considerable height and which, as the water cools when taken from the fire, condenses again by air's pressure and is applied to raise water out of the mine." This account, "as far as discovery goes, entitles Papin to the merit of having first invented the well-known Atmospheric Steam Engine: and probably had he followed up the idea by actual experiment we would have had to record him as the man who first brought it into successful operation. But the greatest merit is not always due to the inventor; thousands of the most brilliant discoveries have perished for want of industry or talent to foster them. The man who first invents and afterwards struggles through every difficulty and by the greatest sacrifices and perseverance brings it into actual practice, perhaps outsteps the projector of the most refined contrivance of which history can boast."*

In these first steam engines we find that the water from which the steam is generated is contained not in a separate vessel but in the cylinder itself, the lower part of which was closed by resting on a metal plate. This plate was heated to change the water into steam, and from the same plate the fire was removed in order to effect condensation. While Papin was undertaking his various experiments and constructing his steam engine models, Thomas Savery was occupied in Cornwall in the construction of a steam engine of his invention. Savery was born at Shilston, in Devonshire, about the year 1650. Whilst little is known of his early life, sufficient remains to show that he was educated as a military engineer and attained the rank of Trench Master. It is probable that Savery's attention was directed to investigations in the construction of a steam engine by his association with the tin mines of Cornwall, where the presence of water in the mines was a constant menace to the miners, and prevented workings being carried any depth below the surface. But the difficulty of raising water from the mines was not merely confined to the metalliferous mines of Cornwall. The working of the majority of English collieries during the seventeenth century was impeded by inefficient drainage, and in no department of mining was the need for improved appliances more felt than in this direction. The more important

* Galloway, *History and Progress of the Steam Engine*, 15.

pits of that period were distributed in watery strata extending downwards to a depth varying from 300 to 600 feet; and the Patent Records bear evidence to the numerous projects devised for the one object of emptying the mines of water.

It will be convenient here to give some indication of the state of the engineering art in relation to the pumping of water from the mines. Chain pumps during the seventeenth century were the most common in the north of England, especially where water power was available for driving them. Chain pumps were of two varieties, the first being the chain buckets, and the second the chain with plates and pipes. The chain of buckets—or, as it was sometimes called, the Egyptian wheel—had been known and used in the East for ages for raising water from deep wells for domestic use and irrigation purposes. As used in mines it consisted of an endless chain with oblong wooden buckets attached at regular intervals, suspended from an axletree extending across the mouth of the pit. As the axletree revolved, the buckets arrived at the top full of water, discharging their contents into a trough as they passed over the axletree, and so down the other side to fill themselves again in the well at the bottom of the pit; precisely in the same way as the modern river dredging machine performs its operation. The chain of plates, on the other hand, consisted of a similarly worked endless chain, which carried circular discs inserted at regular intervals. In ascending the chain passed up through a column of tubes or pipes, which the discs exactly fitted like so many pistons, thus carrying the water above them to the surface.* Where water power was not available for driving water wheels which operated the pumps, the power of horses was employed, and in a subsequent chapter we shall note that George Stephenson, the railway engineer, was employed while a boy to drive the gin-horse at the Wylam Colliery, on the Tyne. The horse, travelling in a circular track, turned a cylindrical drum around which the ropes attached to the buckets revolved.

At this period the tin mines of Cornwall were worked by men with no reserve of capital, many of whom worked in the mines themselves, and who could not provide the pumping

* Galloway, *Coal Mining*, 55.

machinery to keep the mines clear as the workings became deeper and richer lodes were struck. Its absence rendered mining operations so difficult that only a limited amount of work could be undertaken, since the men were forced to work in varying depths of water, and frequently floods became so great that all work had to be stopped. In order to improve these conditions, Captain Savery turned his attention to the design of a more powerful pump, and after experiment decided that the most likely agency was the power of steam. In principle Savery's engine differed little from the theoretical engines which had been proposed by Papin and De Caus, its main feature being the generation of steam in a separate vessel. The description of Savery's engine is contained in a work he published in 1702, entitled *The Miner's Friend*,* after having obtained, in 1699, a patent for the exclusive right of manufacture. M. Arago† speaks as follows of Savery's engine: "The miners showed themselves but little sensible of the compliment. With but one exception, none of them ordered his engines. They have been employed only for supplying water to various parts of palaces, pleasure houses, parks, and gardens; resource having been had to them only when the difference of level to be surmounted did not exceed 12 or 15 metres. It must, besides, be confessed that the danger of explosions would have been very great, if this apparatus had been possessed of the prodigious power which its inventor professed to have gained."

No marked advance was made in the construction and method of operation of the Savery steam engine until the time of Newcomen. He was born in 1663, but comparatively little is known of his early life save that he was by trade an ironmonger and blacksmith, and that he was a native of Dartmouth. Together with his intimate friend, John Calley, he produced an invention which marks the beginning of an

* The full title of Savery's book is as follows: "The Miner's Friend, or an Engine to raise Water by Fire described, and the manner of fixing it in mines, with an account of the several other uses it is applicable unto; and an answer to the objections made against it. By Tho. Savery, Gent. Pigri est ingenii contentum esse his quæ ab aliis inventa sunt. Seneca. London, printed by S. Crouch at the corner of Pope's-head Alley in Cornhill, 1702."

† Arago, *Life of Watt*, 537.

important epoch in the history of steam engineering. The contribution which Newcomen made to steam engineering is briefly described in the account given by Smiles: "Savery created his vacuum by the condensation of steam in a closed vessel, and Papin created his by exhausting the air in a cylinder fitted with a piston, by means of an air pump. It remained for Newcomen to combine the two expedients—to secure a sudden vacuum by the condensation of steam—but instead of employing Savery's closed vessel he made use of Papin's cylinder fitted with a piston."* The actual method of giving effect to this principle was to admit the steam into the cylinder and then spray cold water on its sides, whereupon the steam within was condensed and a vacuum produced, with the result that the pressure of the atmosphere acting upon the top of the piston depressed it to the empty cylinder. In this way the pump rod was raised and the operation repeated. Owing to the length of time required to condense the steam by this method, the operation of the engine was necessarily very slow. But an accident occurred which was destined to alter materially the design of the early engine. "In the beginning of the eighteenth century, the art of boring large metal cylinders and of closing them hermetically by means of movable pistons was yet in its infancy. Thus in Newcomen's first engines the piston was covered over with a layer of water intended to fill the interstice between the circumference of that movable part and the internal surface of the cylinder. To the great amaze of the constructors, one of their engines began one day to move with much more than its ordinary rapidity. After repeated investigations, it was clearly proved that on that day the piston had a hole in it, that cold water fell into the cylinder in very small drops, and that in passing through the steam they caused it rapidly to disappear. From this accidental observation is to be dated the complete abandonment of the application of cold from without and the adoption of the rose-head for the purpose of injecting a shower of cold water through the whole interior of the cylinder at the instant marked for the descent of the piston. The alternate motion thus acquires all the rapidity desirable."† The next important development

* Smiles, *Lives of the Engineers*, "Watt," 63. † Arago, *op. cit.*, 542.

in the design of the steam engine was also the result of a chance occurrence. In the early engines of Newcomen, the various taps or cocks which controlled the entrance of steam or of the cold shower had to be operated by hand, and required constant attention. On one occasion a boy of the name of Potter was responsible for this operation. His desire to accompany his companions at play probably stimulated his mental activity to the invention of a rudimentary valve gear by attaching strings to the two cocks and the beam in such a manner that they opened and closed by the beam's motion as required. It was not long before this crude contrivance was replaced by more appropriate rods and levers, and in 1718 an engine was constructed comprising what was called a hand gear, whereby all the cocks and levers were operated by a rod from the beam; this engine also was the first in which a steel-yard safety valve was used.

Newcomen's first engine was installed in a colliery at Griff, near Wolverhampton, in 1711, and its success was such as to result in repeated orders by colliery owners in the north for similar engines. During the next three years, three more engines were erected in the neighbourhood of Newcastle-upon-Tyne. Newcomen next transferred his energies to the construction of engines for pumping water in the tin mines of Cornwall, and in that district the engines at the Wheal Fortune, Wheal Rose, and Chacewater Mines are outstanding examples of Newcomen's work. At the two latter mines, Joseph Hornblower, who came from Staffordshire, was appointed to superintend the erection of the engines. Hornblower's son, Jonathan, later came into contact with Watt, as a rival builder of steam engines. Cyrus Redding,* one of Hornblower's descendants, states that "how he became in any way connected with Newcomen must have arisen from the latter being at Broms-

* "It may be interesting to know that it required three hands to work Newcomen's first engine. I have heard it said that when the engine was stopped and again set at work the words were passed: 'Snift, Benjy!' 'Blow the fire, Pomery!' 'Work away, Joe!' The last let in the condensing water. Lifting the condensing cock was called 'snifting,' because on opening the valve the air rushing through it made a noise like a man snifting. The fire was increased through artificial means by another hand and, all being ready, the machine was set in motion by a third."—C. Redding, *Yesterday and To-Day* (1863).

grove, when he visited Mr. Potter, who got him to build one of his newly-invented engines at Wolverhampton in 1712." The difficulty Newcomen experienced in Cornwall, as contrasted with his experiences in the northern counties, was the scarcity of coal and its consequent high cost. The consumption of fuel by the Newcomen engine at some of the mines was so excessive that it was doubtful whether steam engines were more economical than horse power. Many men, including Paine, Brindley, and Smeaton, devoted themselves to the work of reducing the coal consumption of the Newcomen engine.

We have to turn to the Continent for an illustration of the enormous saving which resulted from the adoption of the Newcomen engine in certain districts. "M. Belidor, the author of *Architecture Hydraulique*, in his second volume, published in Paris in 1739 (p. 324), gives drawings and a detailed description of a Newcomen engine erected by English engineers at a coal mine at Fresnes, near Conde. The cylinder of the engine was 30 inches in diameter. Previous to its erection, 50 horses and 20 men, working day and night, had been required to raise water from the mine; whereas the engine, with a single attendant, in 48 hours' working cleared the colliery of water for a whole week. As was to be expected, he ascribes the invention to Savery, but he remarks that in one of the letters on the subject which he had received from the Royal Society Mr. Newcomen had been mentioned as having greatly contributed towards bringing it to its present state of perfection."* Unfortunately for the memory of Newcomen among his contemporaries, there were those who disparaged his genius and belittled his invention, and this circumstance, combined with the fact that the invention was brought out under Savery's patent, and consequently regarded by many as merely an improvement of Savery's engine, is probably the principal reason why the father of the steam engine has not been honoured with a loftier niche in the temple of fame.

The construction of the Newcomen engine gave a great impetus to the mining industry, for it made possible the opening of deeper mines. Prior to the middle of the eighteenth century, the number of steam engines in the north of England must

* Galloway, *Annals of Coal Mining*, 244.

	Number.	Diameter of Cylinder (Ins.).
Tyneside, North: Elswick	2	28, 27
Jesmond	4	
Byker	6	42, 42, 60
Heaton	4	
Benton	5	60
Tynemouth Moor	4	60, 42, 75, 70
Newbiggin	4	42, 42, 44, 60
Chirton	1	43
Walker	2	73, 72
West Denton	2	36, 38
East Denton	1	60
Benwell	1	75
Lemington	1	42
Newburn	1	
Throckley	4	36, 13, 48, 60
Wylam	2	47, 60
Gosforth	1	
Tyneside, South: Norwood	1	13
Bushblades	2	42, 52
Rise Moor	1	60
South Moor	1	47
Ravensworth	3	48
Gateshead Fell	1	
Salt Meadows	1	32
Heworth	2	52, 72
River Wear: Ouston	1	48
North Biddick	2	62
Washington	2	62
Chartershaugh	1	36
Lambton	2	42, 64
South Biddick	2	
Newbottle	2	36, 48
Penster Tempest	2	
Morton Hill	2	
Black Fell	1	
Chester Burn	1	28
Fatfield	2	62, 47
South Durham: Auckland	1	48
Northumberland (Tyneside excepted):		
Plessey	1	32
Choppington	1	16
Black Close	1	13
Eshott	1	
Felkington	1	20
Hartley	2	42, 62
Unthank	1	36
Shilbottle	1	42
Fallowfield Lead Mine	1	42
Nottinghamshire: Nottingham	1	60
Cumberland: Workington	1	28
Grey Southern	1	24
Whitehaven	4	28, 36, 42, 42
Parton	1	42
Scotland: Duddingston	1	66
Borrowstones	2	
Total	99*	

* Dunn, *Coal Trade* (1844), 23.

have been few, for we are told that when William Brown* built an engine at Throckley in 1756, "the machine was then a great rarity." Fortunately, a list has been preserved showing the number and distribution of Newcomen's steam engines in the Newcastle-upon-Tyne district in 1769; the number actually at work was fifty-seven, the rest, which were worn out, having been discarded.

"The above list doubtless comprises the bulk of the Newcomen engines erected at collieries up till this date, but it is not by any means complete, as independent records exist relating to others built previously at collieries in the Midland counties, Wales and Scotland. Large numbers of engines had likewise been applied at Cornish mines. According to Price, who wrote in 1778, above sixty engines had been built since the remission of the coal duty by Government in 1741, and more than half of them rebuilt or provided with larger cylinders."

"At the beginning of the eighteenth century every element of the modern type of steam engine had been separately invented and practically applied. The character of atmospheric pressure and of the pressure of gases had become understood. The nature of a vacuum was known, and the method of obtaining it by the displacement of the air by steam and by the condensation of the vapour was understood. The importance of utilizing the power of steam and the application of condensation in the removal of atmospheric pressure was not only recognized but had been actually and successfully attempted by Morland, Papin and Savery."†

The history of the steam engine, from this point onwards, is bound up with the life and work of James Watt, the son of a merchant of Greenock. James was the fourth child of a family of five, and his delicate constitution prevented him from following the ordinary school course, although he was entered as a student of the public school at Greenock, where his attendance was necessarily irregular. While naturally reflective, he

* Brown seems to have been the most eminent viewer in the north n his day. Many of his reports on collieries are preserved in the Museum of the Society of Antiquaries in the Castle of Newcastle. See address on the "Rise and Progress of Coal Mining," by J. B. Simpson, published in the *Colliery Guardian*, December 4, 1896.

† Thurston, *History of the Steam Engine* (1879), 55.

showed remarkable precocity, and we are told that his reflection, as a boy, before a tea kettle, was a prelude to his more serious study on the properties of steam. After an interrupted school career Watt was apprenticed in 1765 to John Morgan, a mathematical and nautical instrument maker, in Finch Lane, Cornhill, where he acquired manipulative skill in the construction of sextants and other instruments. Through ill-health he had to leave London when he had been there less than a year. He returned to Glasgow, but difficulties awaited him there. Although there were no mathematical instrument makers in Glasgow, the co-operators of the various arts and trades, especially of the corporation of hammer men, refused to allow him to set up a workshop on the ground that he was neither the son of a burgess nor had served a recognized apprenticeship within the borough. It was fortunate for Watt that he came under the notice of Professor Dick, Professor of Natural Philosophy at the University of Glasgow, for he was thereby enabled to repair some instruments that had been bequeathed to the University, and so provided an opportunity of demonstrating to the University authorities his superior skill in this art. The final result of this work was that Watt was given accommodation to carry out his trade within the University building and at the same time he was appointed instrument maker to the College. The University professors took a special interest in him, for they keenly appreciated his alert mind and ideas. Among the frequent callers to his workshop were Dr. Black, the chemist, Dr. Dick, and Professor Anderson, the founder of the Andersonian University. The closest friendship Watt developed was with John Robison,* then a student at Glasgow College, afterwards Professor of Natural Philosophy at Edinburgh. Robison gives some indication of the extraordinary diligence with which Watt addressed himself to new problems. "When I was as yet a young student," he wrote, "I had the vanity to think myself a pretty good proficient in my favourite studies of mathematical and mechanical philosophy, and on being introduced to Watt, was rather mortified at finding him so much my superior. Whenever any puzzle came in the way of any of us, we went to

* See footnote, p. 111.

Mr. Watt. He needed only to be prompted; everything became to him the beginning of a new and serious study, and we knew that he would not quit it till he had either discovered its insignificancy or had made something of it. On one occasion the solution of a problem seemed to require the perusal of Leupold's *Theatrum Machinarum*, and Watt forthwith learnt German. At another time, and for a similar reason, he made himself master of Italian. When to the superiority of knowledge, which every man confessed, in his own line, is added the naïve simplicity and candour of Mr. Watt's character, it is no wonder that the attachment of his acquaintances was strong."

Watt attributes his introduction to the steam engine to his friend Robison: "My attention was first directed, in the year 1759, to the subject of steam engines by the late Dr. Robison, then a student in the University of Glasgow, and nearly of my own age. He at that time threw out an idea of applying the power of the steam engine to the moving of wheel-carriages, and to other purposes; the scheme was not matured and was soon abandoned on his going abroad."* In the collection of models belonging to the University of Glasgow was a small model of a Newcomen steam engine which had never worked satisfactorily. In 1763 Professor Anderson gave it to Watt to repair, and while engaged on it he made a very serious study of the problem of the steam engine. It was not long before Watt fully appreciated the limitations of the Newcomen engine, which was mainly the inefficiency resulting from the cylinder being alternately made hot by the steam entering, and made cold by the condensing water. After long and careful thought, he hit upon the idea of improving the Newcomen engine to the extent of separating the cold condenser from the hot steam cylinder, and it is this apparently simple expedient which constitutes the basis of Watt's epoch-making invention. It is of interest to record the manner in which the idea occurred to Watt as he related it many years after to Mr. Robert Hart. "I had gone to take a walk on a fine Sabbath afternoon. I had entered the Green by the gate at the foot of Charlotte

* Robison, *Mechanical Philosophy* (ed. Brewster), II. 113. It is interesting to note, however, that in his patent of 1784 Watt describes a portable steam engine for moving wheel carriages.

Street and had passed the old washing-house. I was thinking upon the engine at the time and had gone as far as the herd's house when the idea came into my mind that as steam was an elastic body it would rush into a vacuum, and if a communication were made between the cylinder and an exhausted vessel, it would rush into it, and might be there condensed without cooling the cylinder. I then saw that I must get rid of the condensed steam and injection water if I used a jet, as in Newcomen's engine. Two ways of doing this occurred to me. First, the water might be run off by a condensing pipe, if an off-let could be got at the depth of 35 or 36 feet, and any air might be extracted by a small pump. The second was to make the pump large enough to extract both water and air." He continued: " I had not walked further than the golf-house when the whole thing was arranged in my mind."*

Although Watt had conceived very completely the idea of separating the condenser from the engine, it took many years of laborious effort to give effective practical application to his idea. He first of all made a working model embodying his invention, and then, in August, 1765, constructed a larger engine on the same principle, in which task he was assisted by John Gardiner. The lack of skilled mechanics was very pronounced, as the result of which his work was greatly retarded; the only engineering workmen available in Glasgow were blacksmiths and tinners, who were not accustomed to the fine work necessary for the successful construction of a steam engine. Moreover, in his early efforts Watt was continually faced with financial difficulties, and for many years his friend Dr. Black assisted him to his uttermost in this direction. It was later through Black's influence that Watt was introduced to Dr. Roebuck, of Kinneil, the founder of the Carron Iron Works. The latter was so confident of the success of Watt's work that in 1765 he undertook to pay debts to the sum of £1,000 in return for which he was to have an interest in the new steam engine patent. After taking out the patent for his new engine Watt proceeded to try it at Kinneil, and, in order to preserve as great secrecy as possible, selected a little secluded

* Hart, " Reminiscences of James Watt," in *Transactions of the Glasgow Archæological Society*, 1859.

outhouse as the scene of his operations. It took six months to construct the engine, which was completed in September, 1769, but it did not prove very successful; and writing to Small, Watt complains: "You cannot conceive how mortified I am with this disappointment. It is a damned thing for a man to have his all hang by a single string. If I had wherewithall to pay the loss I don't think I should so much fear a failure; but I cannot bear the thoughts of other people becoming losers by my schemes; and I have the happy disposition of always painting the worst."†

Watt made little further progress in the development of his steam engine until he became associated with Matthew Boulton, who was an affluent owner of an engineering works in Soho, Birmingham. The Soho works was one of the largest of its kind in England, and a variety of products was manufactured, including steel work, plated and silver goods, astronomical clocks, and paintings on glass. The machinery at Soho was driven by a water-mill which was uncertain in its operation owing to the drought which often occurred during summer months. It was at such times that a horse mill had to be connected with the water-mill, involving not only considerable delay, but very heavy expense. Small wonder that under the circumstances Matthew Boulton became interested in the possibilities of the steam engine and invited Watt to visit him, which he did in the summer of 1767. While inspecting Boulton's works Watt was greatly impressed with the high-grade tools which he possessed and the highly developed skill of most of his workmen, and felt that if his steam engine could be erected under such desirable conditions it would promise to be much more successful than if constructed under more crude conditions at Glasgow. After much correspondence, discussion, and scheming, Watt finally agreed to a proposal that the drawings of his engine should be sent to Soho and a sample engine constructed at these works. Consequently in 1770 patterns were constructed and sent to the iron works at Coalbrookdale to be cast, but so imperfect were the castings that the work had to be abandoned. Finally, after the financial failure of Dr. Roebuck, Watt arranged for the engine that had

* Quoted by Smiles, *Lives of the Engineers*, "Watt," 114, 115.

been erected in the outhouse at Kinneil to be transferred to the works at Soho, Birmingham, where it might be constructed under more desirable conditions. "As I found the engine at Kinneil perishing, and as it is from circumstances highly improper that it should continue longer there, and as I have nowhere else to put it, I have this week taken it to pieces and packed up the ironwork, cylinder, and pump ready to be shipped to London on its way to Birmingham, as the only place where the experiments can be completed with propriety. I suppose the whole will not weigh above four tons. I have left the whole of the woodwork until we see what we are to do."*

When Watt proceeded to Birmingham he had spent about nine years in the development of his invention, and five years had passed since he had taken out his patent. At this time Watt's association with Boulton consummated in the foundation of a partnership which was entered into between them, and after the patent rights of Watt's steam engine invention had been extended for a period of twenty-five years by Act of Parliament, they began under the joint names of Boulton and Watt to manufacture steam engines at the Soho factory, Birmingham. Speaking of the partnership, and particularly of Boulton, Watt in his notes added to the last edition of Robison's *Essay on the Steam Engine* wrote: "In 1774-5 I commenced a partnership with Mr. Boulton which terminated with the exclusive privilege in the year 1800 when I retired from business; but our friendship continued undiminished to the close of his life. As a memorial due to that friendship, I avail myself of this, probably the last, public opportunity of stating that to his friendly encouragement, to his partiality to scientific improvements, and his ready application of them to the processes of art, to his intimate knowledge of business and manufacture, to his extended views and liberal spirit of enterprise, must in a great measure be ascribed whatever success may have attended my exertions."

The first engine to be manufactured at Soho was to the order of one John Wilkinson, and was used to blow the bellows of his iron works at Broseley. Watt personally superintended

* Watt to Small, May 20, 1773, Boulton MSS., quoted by Smiles, *op. cit.*

the erection of this engine at Broseley, and great care was taken in every detail of the construction. It was erected and ready for use about the beginning of 1776, and worked entirely satisfactorily. Many of Wilkinson's iron-manufacturing friends who had contemplated installing Newcomen engines delayed placing their orders until they had had an opportunity of witnessing the performance of Watt's engine. They were all well satisfied with its success, and Boulton and Watt secured wide publicity throughout the Midland counties. Even when the steam engines were erected and operating satisfactorily, Boulton and Watt were frequently harassed by the lack of knowledge and inexperience of the mechanics of the day who were put in charge of the engines. In order in some measure to compensate for the inexperience of the engine attendants, Watt endeavoured to simplify the construction of the engine as much as possible so that it could be operated and repaired by an average workman. We are correct in concluding, therefore, that Watt's engine, like Newcomen's, made its début in the Midland counties, particularly in the south Staffordshire coalfields, and it appeared here before it was adopted in the metalliferous mines of Cornwall, and a considerable period before it was generally adopted in the North of England. Writing to Smeaton in a letter dated April, 1776,* Watt informs him that they " have now two large engines going, one about ten miles from Birmingham, the cylinder 50 inches diameter; intended to work a 14¼ inches working barrel, to lift water from 100 yards depth; but the pit is only sunk to 40 yards at present." The other engine was the one we have already referred to at the iron foundry in Shropshire.

" In organizing the works at Soho, Boulton and Watt found it necessary to carry division of labour to the farthest practicable point. There were no slide-lathes, planing-machines or boring tools, such as now render mechanical accuracy of construction almost a matter of certainty. Everything depended upon the individual mechanic's accuracy of hand and eye; and yet mechanics generally were then much less skilled than they are now. The way in which Boulton and Watt contrived partially to get over the difficulty was to confine their workmen

* Farey, *Steam Engine*, 320.

to special classes of work and make them as expert as possible. By continued practice in handling the same tools and making the same articles they acquired great individual proficiency. 'Without our tools and our workmen,' said Watt, 'very little could be done.'"* However, as the reputation of the Boulton and Watt engines spread throughout the mining districts, orders in increasing numbers were received for their construction. "Repeated trials showed that, with equal power, they consumed three-fourths less fuel than Newcomen's had done. The moment this was known the new engines came rapidly into use in all the mining districts and especially in Cornwall. Boulton and Watt received† as their remuneration the third part of the value of the whole fuel which was saved by each of their engines. You may judge of the commercial importance of the invention by the following well attested fact: 'In Chacewater mine alone, where three pumps were at work, the proprietors found their account in purchasing up the rights of the inventors for an annual sum of £2,400. Thus in one concern alone, the use of the condenser in lieu of injecting water into the cylinder, had effected a saving in fuel of more than £7,200 per annum.'"‡

Watt very early realized the desirability of applying his engine to produce a rotary motion, as distinct from its see-saw motion required for mine-pumping purposes. This necessitated the use of a crank, and in the summer of 1780 a model crank engine was under construction at Soho, but one of the Soho workmen, Cartwright, the pattern-maker, was unable to preserve the secret of the crank, and during an outburst of volubility at the Wagon and Horses Inn, near Soho, proceeded to sketch the principle of the crank for the benefit of his companions. Watt had never thought of taking a patent out for his crank, regarding it as a very old and common idea.

* Smiles, *Lives of the Engineers*, "Watt," 195, 196.

† "Stipulated to receive, but in fact did not receive nearly that proportion. Where the agreement was not for a fixed sum the savings were computed from the number of strokes made by the engine; to ascertain which a small instrument or piece of clock-work, called a counter, was invented by Mr. Watt, which being locked up in a box and fixed upon the working beam told, when opened, the number of strokes the engine had made since the last inspection."

‡ Arago, *op. cit.*, 549.

"The true inventor of the crank rotative motion was the man who first contrived the common foot-lathe; applying it to the engine was like taking a knife to cut cheese which had been made to cut bread." But an eavesdropper was quick to transmit the idea of the crank, sketched by Cartwright, to other quarters, and we find on August 23, 1781, the crank invention patented by James Pickard, a Birmingham button-maker, with whom Matthew Washborough of Bristol made an arrangement to use the patent in the engines which the latter constructed at his works. As soon as Watt heard of the incident he suspected that Matthew Washborough, the Bristol mechanic, was responsible for capturing the idea. Watt was consequently compelled to devise other means for effecting a rotary motion, and so fertile was his inventive mind that by October 5, 1781, he had patented five different methods for producing rotary motion from his engine, although the one eventually chosen was the well-known device the "sun and planet" wheels, invented by William Murdoch. The rumours that the Hornblowers in Cornwall had invented a new engine to supersede the Boulton and Watt engine alarmed Watt. The first such engine was erected in 1782 at the collieries at Radstock, in Somersetshire, by Jonathan Hornblower, and was the first of his compound steam engines. Although the engine does not appear to have been a success, nevertheless Watt proceeded to Bristol and warned Hornblower's employers and the public that the engine was an infringement of his own patent. Returning from Somerset Watt proceeded to supervise the manufacture of rotary engines of his own design at the Soho works, Birmingham. Boulton at this period realized the limited field for pumping engines and was anxious to apply the steam engine to the winding of coals, although Watt appeared to have viewed this with dubiety. In this connection we find that, while Boulton was in Dublin, Watt wrote him in the following words: "Some people at Burton are making application to us for an engine to work a cotton mill; but from their letter and the man they have sent here I have no great opinion of their abilities. . . . If you come home by way of Manchester please not to seek for orders for cotton mill engines because I hear that there are so many mills erecting on powerful

streams in the north of England that the trade must soon be overdone and consequently our labour may be lost." Watt's first rotary engine was erected in 1782 at the corn mill of Mr. Reynolds, in Ketley. It was shortly followed by other orders, and soon engines of this type were used for polishing glass, grinding malt, rolling iron, and other industrial processes. Not yet, however, was the steam engine ripe for producing a smooth and regular rotative motion. Its force was still only exerted in one direction.

The idea of producing a rotary motion was not new, as it had been considered by Papin, and was thus as old as the engine itself. But at this period it was specially adapted to the see-saw motion required for pumping: "the piston pulling up the pump-rods with the water, and the pump-rods again, by their preponderance of weight, pulling up the piston on admission of steam under it," and not adapted for producing rotary motion. In short, being a single-acting engine, it could exert a "pull" but not a "push," and complex mechanism was required to overcome this deficiency. By a great stroke of genius Watt at length mastered this difficulty. "He arranged to produce a vacuum alternately above as well as below the piston, the steam being at the same time applied on the opposite side, thus making the engine work equally in both directions, or in other words, double-acting. This form of engine he patented on March 12, 1782. This was the crowning improvement of the steam engine, and at once solved the difficulty of applying it directly to produce a continuous rotative motion."* At first Watt employed a toothed rack and sector in lieu of the chain previously used, to enable the double-acting engine to push and pull equally, but this arrangement was superseded soon after by the invention of the parallel motion which he patented in April, 1784. From this period onwards Watt's engine ceases to be almost exclusively a mining appliance used for raising water, and enters a much wider field. "The first steam engine grinding wheel at Sheffield was set a-going in 1786. The engine for Albion Mills, London, was built by Boulton and Watt also in 1786—an engine which Mr. Muirhead speaks of as one of the first completed for sale

* Galloway, *Annals of Coal Mining*, 80.

which combined all Watt's improvements; while at nearly the same date we hear of Mr. Arkwright's cotton factory at Manchester being worked by a steam engine. And so its use continued to extend as a source of power for all purposes, and it affords a curious illustration of the force of use and wont that, notwithstanding Watt's splendid improvements on the Newcomen engine, even in applying his engine to duties so different from pumping, as driving the machine of a mill, or blowing the blast of an iron-furnace, he continued to make use of the beam, or pump-handle."* Watt also invented the "indicator," a device for recording diagrams showing the relation between the pressure in the steam engine cylinder and the position of the piston for each point of travel of the piston, and giving, as it were, a complete picture of what has happened inside the cylinder.

Watt's assistant, William Murdock, introduced very many valuable improvements into the steam engine, an important one being the slide valve as a means of admitting and releasing the steam. We find Murdock, who had entered the employ of Boulton and Watt at their works in Soho in 1777, associated with Watt in the erection of his engine in Cornwall in 1779. He was a most competent workman and skilled mechanic, and whenever delicate and accurate work required to be done, Watt invariably enlisted Murdock's aid. It was Murdock who invented the "sun and planet" motion, which was later adopted by Watt in securing rotary motion. Later in life Murdock constructed a model locomotive, the first of its kind to be built in this country, but reference is made to his work in a later chapter, as also to his invention of lighting by gas.

Watt's experience taught him that in steam-engine construction two fundamental principles must be observed. "The first, that the temperature of the cylinder should always be the same as that of the steam which entered it, and consequently that when the steam was condensed, it would be cooled to as low a temperature as possible." Although since Watt's time many improvements have been introduced into the construction of the steam engine, yet efforts made to improve its efficiency have all been in the direction of the more complete realization

* *Ibid.*, 303.

of these two fundamental principles which were enunciated by Watt himself. The greatest improvement in the steam engine which has taken place since the time of Watt has been the introduction of compound expansion. What would now be called a compound engine was introduced by Hornblower, and later by Woolf. It had two cylinders, one of small diameter and one of large diameter. Steam was admitted into the smaller cylinder, where it expanded a little, and was then passed over into the large cylinder, where the expansion was completed. The great advantage of compound expansion is that, the steam being expanded to a limited amount in each cylinder, the fall of temperature in each cylinder is consequently reduced, and the inefficiency resulting from heating new steam entering a very cold cylinder is thereby reduced to a minimum.

The invention of the steam engine had a profound effect on the mining industry; indeed, as a recent writer has pointed out, there is a marked interdependence between the two industries of engine-building and coal-mining. "Coal could not have been won without the steam engine; the steam engine could not have been worked without coal. Automatic machinery could not have been developed without steam power; the steam engine could not have been constructed without machine tools. Neither engine nor machinery could have been developed without iron, and the iron could not have been wrought without mechanism and power. It was one great cycle of interacting and reacting forces, no one of which could have come to perfection without the aid of the rest."*

We have hitherto considered the history of the reciprocating steam engine which derives its power from the static force of steam expanding behind the piston. This force presses on the piston and drives the engine. A fundamentally different type of engine is the steam turbine, the first of which was Hero's engine, or Hero's reaction wheel. In this type of rotary engine expansion causes high velocity in a jet of steam, and consequently kinetic energy is imparted to the steam particles. This steam is caused to impinge against a series of blades arranged around the periphery of a wheel that is free to move about its centre. The force of the steam acting on the blades

* Wood, *Industrial Engineering in the Eighteenth Century*, 17, 18.

causes the wheel to rotate and so do work. The action is somewhat similar to the manner in which a stream of water rotates a water-wheel. Early suggestions and patents relating to the principle of the steam turbine were undertaken on the Continent by De Kempelen in 1784 and Francis Bresson in 1852. In 1828 Birstall, in order to obtain a reverse motion in the engine, suggested that a second set of arms mounted in the opposite direction to the first should be built on the same shaft, and in 1836 Hale's patent provided for the steam after having done its work on the first wheel to be directed on to a second wheel. Although by Hale's patent the compound turbine is proposed, it was not until 1858 that a really satisfactory compound steam turbine was constructed, and it was covered in that year by Harthan's patent.

The possibilities of the steam turbine were not fully explored until Sir Charles Algernon Parsons produced the first steam turbine of practical and commercial importance. Parsons was brought up in a scientific atmosphere, having received his early education privately, and afterwards proceeded to Dublin University and then to Cambridge, where in 1876 he took high honours in the Mathematical Tripos. Upon the completion of his University training, Parsons became a pupil at the Elswick Works, and gave early indication of his inventive genius by the invention of various valve motions, as well as of a four-cylinder rotary engine with revolving cylinders. It was about this time that the steam turbine problem attracted Parsons' attention. De Laval had produced on the Continent the first steam turbine in which a jet of steam impinged with a high velocity upon the blades of the wheel, which in consequence was made to rotate. In this way, as earlier explained, the steam could be economically used only by running the turbine at a very high speed. In 1884 Parsons dealt with the problem in a different way. It seemed to him that moderate surface velocities and speeds of rotation were essential if the turbine was to receive general acceptance as a prime mover. Therefore he decided to split up the fall in pressure of the steam into small expansions over a large number of turbines in series, so that the velocity of the steam nowhere should be great. This principle of compounding steam turbines is now universally

used in all except very small engines where economy of steam is of secondary importance. The first Parsons turbine built, in 1884, on this principle is now only of historical interest, and is appropriately placed in the South Kensington Museum. It developed 20 horse-power at 18,000 revolutions per minute, and was coupled directly to a small dynamo. The Parsons turbine made its first important public appearance at the Royal Jubilee Exhibition at Newcastle-on-Tyne, in 1887, when the dynamos generating the electricity for the illumination of the exhibition courts were driven entirely by steam turbines. "The smooth running and compactness of the machines used there received universal admiration, but unfortunately their daring novelty, combined with their more serious defect of a large steam consumption, caused engineers to regard them more in the light of mechanical toys." Their steam consumption was exceedingly high, and was round about 36 pounds of steam per horse-power hour, as compared with the consumption of modern large turbines of 12 pounds of steam per horse-power hour.

We have already seen that the type of steam engine which made any claim to efficiency was of the condensing type, in which the steam, after doing its work in the cylinder, was exhausted into a condenser at a pressure considerably below that of the atmosphere instead of being allowed to escape into air at atmospheric pressure. But up to 1891 the steam turbine was of the non-condensing type, and it was only in that year that Parsons decided to build the first condensing type turbine, which was constructed in the following year. Tests on this engine, conducted by Professor Ewing, of Cambridge University, in 1894, showed the engine to be a rival of the reciprocating type, and removed altogether out of the realm of the mechanical toy. The invention of the turbine necessitated also the invention of a higher speed dynamo to be driven by it. In those early days little was known of the theory of the dynamo; it was the late Professor J. Hopkinson who put the theory on a firm footing. The improvement of high-speed electrical machinery has gone hand in hand with the advance of the steam turbine.

Sir Charles Parsons was not content with conquering on land; he resolved to conquer on the ocean also. It was in the

beginning of 1894 that his idea in that direction took shape, and three years later he had completed the famous *Turbinia.* Although this vessel was only 100 feet long, 9 feet beam, and 44 tons displacement, she attained the then unprecedented speed of 34 knots. She was followed by the *Viper* and *Cobra,* the engines for which were built at the Parsons' Marine Steam Turbine Company's works at Wallsend, the former making over 36½ knots on trial. Again, as there had been in the use of the turbine on land, there was an interregnum in its application at sea, with a time of difficulty and stress, but Parsons overcame all obstacles, and since 1905, when the *Amethyst* with turbines beat the *Topaz* with reciprocating engines, the progress has been rapid beyond anticipation. Now there is not a single war vessel belonging to this country—and practically none abroad—that is not being engined with steam turbines. Similar progress is characteristic of the mercantile marine: all great ocean liners are being fitted either wholly or partly with steam turbines. Those partly so driven are due to the genius of Sir Charles, who saw the advantages of the combination with reciprocating engines in certain instances. Within the past few years a further great development has taken place by connecting the turbines to the propeller by gearing, an invention which is only in its infancy, and possesses great possibilities. Apart from the great advances made in recent years in the steam turbine from the point of view of its steam consumption per unit of energy, the small space occupied by the turbine is of considerable importance, as for equal powers a smaller capital outlay for building is required in the case of the turbine. Moreover, even in the case of the smaller types of steam turbines the cost is very little greater than that of an efficient reciprocating engine of the same size, while the larger turbines are much cheaper than reciprocating engines.

CHAPTER VII

RAILWAY AND LOCOMOTIVE ENGINEERING

THE beginning of the modern railway in this country is to be found in the rough planks that were laid on the English roads of the seventeenth century adjacent to the coal-pits. It would appear that this device was first adopted round Newcastle for the carriage of coal from the pits to the River Tyne. "The manner of the carriage," wrote Roger North, who visited Newcastle in 1676,* "is by laying rails of timber . . . exactly straight and parallel; and bulky carts are made with four rowlets fitting these rails; whereby the carriage is so easy that one horse will draw down four or five chaldrons† of coals." The rails were apparently of German origin, and were merely devices for counteracting the bad state of the roads, and the planks of wood were placed at the bottom of the ruts that soon became worn in the roads by the passage of the crude waggons of that period. It is supposed that wooden rails were first employed in this manner by Beaumont about 1630. More than a century later Arthur Young drew attention to the increase in the numbers of this type of railway. "The coal-waggon roads from the pits to the water are great works, carried over all sorts of inequalities of ground, so far as the distance of nine or ten miles. The track of the wheels is marked with pieces of timber let into the road for the wheels of the waggon to run on, by which means one horse is enabled to draw, and that with ease, fifty or sixty bushels of coals."‡ These rails are said to have had a length of about 6 feet, and were 5 or 6 inches in thickness, with a breadth of about the same proportions. They were pegged down to sleepers placed across the track at a distance of about 2 feet apart, so that

* *The Lives of the Norths* (ed. Jessopp, 1890), I. 176.

† From 10·6 to 13·2 tons.

‡ Young, *A Six Months' Tour through the North of England* (ed. 1771), III. 9.

one rail reached across three sleepers. The space between the sleepers was filled in with ashes or small stones, to protect the feet of the horses. The waggons were in the form of a hopper, being much broader and longer at the top than the bottom. At first all four wheels of the waggon were made either of one entire piece of wood or of two or three pieces of wood fastened together, the rim in either case being so shaped as to have on one side a protection, or flange, which would keep the wheel on the rails.*

The first development in the wooden rail was the fastening on to it of a second rail, the whole producing what was known as a "double way," so that this second rail could be removed when worn out without interfering with the sleepers. "The double rail, by increasing the height of the surface whereon the carriage travelled, allowed the inside of the road to be filled up with ashes or stone to the under side of the upper rail, and consequently above the level of the sleepers, which thus secured them from the action of the feet of the horses."† A second improvement was the protection of the wooden rails from undue wear by covering them with a thin sheet of wrought iron, and lines so constructed were called "plateways"; it was not long before this experiment was followed by the complete replacement of the wooden rail by a cast-iron one. The first adoption of the cast-iron rail is supposed to have taken place, about 1738, at the collieries in Whitehaven. That rails of this type were being used in 1767 is confirmed by an entry in the books of the Coalbrookdale Iron Works, Shropshire, to the effect that a few tons of iron rails were cast as an experiment and afterwards used to form a road. These experimental rails were flanged on the inside, and being long and unsupported in the centre, they were frequently broken by heavy waggons. This defect was remedied by constructing smaller waggons for carrying lighter loads.

In 1785 Mr. William Jessop, engineer to a proposed railway between Nanpantan Collieries and Loughborough in Leicestershire, contemplated the idea of a flange cast upon the rail itself, but this plan he abandoned on account of opposition

* Wood, *A Practical Treatise on Railroads* (1825), p. 190. Quoted by Pratt, *History of Inland Transport*.

† Wood, *ibid.*

from the commissioners of a turnpike road which had to be crossed by the railway. The commissioners maintained that the flange would constitute a danger to traffic. Mr. Jessop, in order to overcome the objections of the turnpike commissioners, proposed later (in 1788) to cast the flange upon the wheel instead of on the rail, which latter would be cast flat: this practice was soon universally adopted. "The substitution of the flanged wheel for the flanged plate was an organic change which has been the forerunner of the great results accomplished in modern travelling by railway."* Cast-iron rails continued to be used for a number of years after Jessop's improvement, wrought-iron not being adopted until after 1820, in which year John Birkenshaw, of the Bedlington Iron Works, devised a method for rolling iron rails. At the same time, however, the scarcity of wood, with its corresponding increase in cost, was forcing the adoption of iron rails in place of wood. A writer in 1810 observes: "Of late years, on account of the high price of wood, iron railways have been substituted."† In the earliest railways wooden sleepers had been used and the rails bolted or pierced to them; but in 1797, when laying a railroad at the Lawson Colliery at Newcastle-on-Tyne, Barnes introduced stone blocks instead of wooden sleepers. "Constructed with flanged rails, or 'plates' fixed on stone block sleepers, the line was available for any ordinary cart or waggon of the requisite gauge. The conveyances mostly used on it were four-wheeled trucks, about the size of railway constructors' waggons. They belonged either to local traders or to carriers who let them out on hire, it being doubtful whether the company had any rolling stock of their own. The motive power was supplied by horses, mules or donkeys. Chalk, flint, fire-stone, fuller's earth, and agricultural produce were sent from Croydon—then a town of 5,700 inhabitants—to the Thames for conveyance to London. The return loading from the Thames was mainly coal and manure. Two sets of rails were provided, and there was a path on each side for the men in charge of the horses."‡

The early iron railways of England were private under-

* Brunlees, Presidential Address, British Association (Mechanical Science Section), 1883.

† Bailey, *General View of the Agriculture of the County of Durham*, 294.

‡ Pratt, *op. cit.*, 223.

takings constructed for the most part by colliery owners for the purpose of facilitating the transport of coal. The first public railway was the Surrey Iron Railway, the Act empowering its construction being passed in 1801. This line connected Croydon with the Thames at Wandsworth, and was designed for "the advantage of carrying coals, corn and all goods and merchandise to and from the Metropolis."* It is worthy of note that those who framed the Act of 1801 contemplated the use of horse power only for motive purposes. After the precedent of the canals, the tracks were laid down for general use by carriers, and passenger traffic was neither expected nor catered for. Persons might, however, with the approval of the company, and after paying certain tolls, construct passenger carriages to run on the rails.

From the opening of the nineteenth century onwards improvements in the track gave place to improvements in the motive power for drawing waggons along the railroads. Early experiments were made in the use of sails, but met with no success, though the method was employed by Sir Humphrey Mackworth, a coal-mine owner at Neath in Glamorganshire. A more promising scheme was the application of steam power for traction purposes. Experiments were carried out at the same time in many countries, and actually the first practical steam carriage was constructed by a French engineer, Cugnot, and tried in the streets of Paris. One of the early British experimenters on the steam engine was William Murdock, born on August 21, 1754, at Bellew Mill, in the village of Lugar in Ayrshire, when his father tenanted both the mill and the adjoining farm. During his work as miller Murdock's father had developed a marked skill in millwrighting, and his mechanical ingenuity had found expression in the invention of toothed bevel mill-gearing. As a boy William Murdock, who doubtless inherited from his father an interest in things mechanical, had his attention directed to the problem of locomotion, when he helped his father to construct a wooden horse, the forerunner of the modern bicycle. In 1777, at the age of twenty-three, young Murdock left the secluded village of Lugar to seek his fortune in Birmingham, and entered the service of Boulton

* Surrey Iron Railway Act, 1801.

and Watt at the Soho works. It is on record that when Boulton interviewed the young applicant for employment, Murdock, doubtless somewhat nervous at the outset, dropped his hat, and the curious sound it made in striking the floor attracted Boulton's attention. He discovered that the hat was made of "timmer,"* and had been shaped "in a bit lathey" of Murdock's own making. Probably this information alone satisfied Boulton as to the young man's suitability for employment at Soho, for he engaged him at a wage of 15s. per week. The next year Murdock was sent to Cornwall to take charge of the Boulton and Watt engines used in pumping at the Cornish mines, and he entered upon his work with great pluck and determination. Watt tells us that on one occasion some men from the mines "having attempted to bully him, he quietly locked the door of the room in which they were assembled, stripped, and, making a dexterous use of those arms with which Nature had supplied him, administered to more than one of their number a lesson of persuasive efficacy, such as they would never forget, and such as he was never called upon to repeat. He was, in truth, of Herculean proportions, and in muscular power nearly unrivalled."†

Despite his occupation at the mines, Murdock found time to devote to the problem of the steam locomotive, and constructed a working model of a steam road carriage. It was quite a small machine, standing about 14 inches high, and was 19 inches long. "An attentive examination of the model well repays one and reveals many beautifully simple contrivances, showing Murdock's genius for the adaptation of simple means to secure his desired ends. . . . This is probably the earliest slide valve used in a steam engine, as at the date of its construction Boulton and Watt did not use Murdock's **D** slide in their engines, but still adhered to disc valves, with much driving gear. . . . The safety valve is let into the boiler near the steam cylinder, and it is held down by a little tongue of metal—a very efficient and simple contrivance."‡ This engine "was seen in 1784 by persons still living [in 1850] drawing

* Timber.

† Muirhead, *The Origin and Progress of the Mechanical Invention of James Watt*, 426.

‡ Quoted by Hunt in *A History of the Introduction of Gas Lighting*, 31, 32.

a small model waggon round a room in his [Murdock's] house at Redruth, where he then resided. At the time that Mr. Murdock was making his experiments with his locomotive engine, he greatly alarmed the clergyman of the parish of Redruth. One night, after returning from his duties at the mine, he wished to put to the test the power of his engine, and to do this had to resort to the walk leading to the church. This was rather narrow, but kept rolled like a garden walk, and was bounded on each side by high hedges. The night was dark and he sallied out with his engine, lighted the lamp under the boiler, and off started the locomotive with the inventor in full chase after it. Shortly after he heard cries of terror; it was too dark to perceive any object, but he soon found that the cries for assistance proceeded from the worthy pastor, who, going into town on business, was met in this lonely road by the fiery monster, whom he subsequently declared he took to be the Evil One, *in propria persona*."*

An accident of chance prevented Murdock from patenting his steam locomotive. The story is related in a letter† written at Truro nearly two years later by Boulton to Watt: "I arrived at Exeter on Wednesday night, and set out from there on Thursday afternoon to sleep at Oakhampton. About one mile on this side of Exeter I met three of the Foxes going to a general Quakers' meeting at Gloucester, and in the same coach was William Murdock. He got out and we had a parley for some time. He said he was going to London to get some men, but I soon found he was going there with his Steam Carriage to show it and to take out a patent, he having been told by Mr. Wilkinson what Sadler had said, and he had likewise read the newspaper Symington's puff, which had rekindled all William's fire and impatience to make Steam Carriages. However, I prevailed upon him readily to return to Cornwall by the next day's diligence, and he accordingly arrived here this day at noon, and since which he hath unpacked his carriage and made it travel a mile or two in River's great room in a circle, making it carry the fire shovel, poker and tongs. I think it fortunate that I

* Buckle, "On the Inventions and the Life of William Murdock," in *Proceedings of the Institution of Mechanical Engineers*, 1850.

† First published by Hunt, *op. cit.*, 32, 33.

met him, as I am persuaded that I can either cure him of the disorder, or turn the evil to good; at least I can prevent a mischief that would have been the consequence of his journey to London." Apparently Boulton succeeded in his efforts, since Murdock never constructed his locomotive in a practicable form. It was Richard Trevithick, Murdock's pupil, who constructed the first English locomotive. In August, 1802, Trevithick built a railway locomotive at Coalbrookdale, which was followed in 1804 by another locomotive for the Pen-y-darren tramroad, near Merthyr Tydvil. The latter locomotive contained a single horizontal cylinder 8¼ inches diameter with a 4 feet 6 inches stroke, and, in order to keep the cylinder warm, part of it was enclosed in the boiler and the remainder surrounded by a steam jacket. Although the steam after being used in the cylinder was exhausted through the chimney, this device appears to have been used merely as a convenience and not for the purpose of inducing chimney draught. This view is confirmed by the fact that in the patent specification which Trevithick drew up in connection with his locomotive, reference is made to bellows for blowing the fire, and it is clear, therefore, that the inventor was unfamiliar with the exhaust steam blast. Although Trevithick made provision for a safety valve in the design of his engine, this was not included when the locomotive was built, and owing to this deficiency the engine came to an untimely end by explosion. The next locomotive constructed by Trevithick, called "Catch-Me-Who-Can," ran in 1808 on a small elliptically shaped railway in Euston Square, London, where during the weeks of the exhibition it was visited by many people. The engine attained a speed of 12 miles per hour, but at the end of a few weeks' running, a rail broke and the engine overturned and was damaged. Trevithick had now come to the end of his means, and was compelled to give up his locomotive demonstration, and there is no record to show that he ever returned to this branch of engineering. The drawings of Trevithick's Coalbrookdale locomotive were used for the construction of a locomotive built to the order of Mr. Blackett, owner of the Wylam Collieries. The engine, which had a single cylinder 7 inches diameter and a 3-foot stroke, and fitted with a fly-wheel, weighed 4½ tons. Although

originally intended for use on the Wylam Railway, it was never employed for that purpose, but was installed in a Newcastle foundry for supplying a cupola with an air blast.

During the early stages of the development of the steam locomotive, the idea was current that smooth wheels could never be adopted on smooth lines, as the wheels would simply turn round without moving along the rail. J. Blenkinsop, of the Middleton Colliery near Leeds, appears to have been responsible for this erroneous idea; and on April 10, 1811, obtained a patent for a self-propelling steam engine worked by means of a cog-wheel, the teeth of which would fit into teeth cut into the rail, thus producing the modern rack-and-pinion mechanism. There is little doubt but that this patent, by influencing subsequent designers, retarded the development of the steam locomotive. Blenkinsop had an engine constructed embodying his patent, and although it is generally known as Blenkinsop's, it was constructed by Matthew Murray, an expert mechanic of Leeds. This locomotive, which ran for the first time on August 12, 1812, and cost £400 to construct, contained a cylindrical boiler with convex ends through which a single flue ran, turned upwards in the front to form the chimney. The locomotive was used for the haulage of coal on a track about 3½ miles long, and continued in use for about twenty years.

We have already noted that Blackett of the Wylam Colliery ordered a locomotive from Trevithick, but did not use it on his colliery tramroad. Blackett determined, however, to "make a trial of steam haulage on his plateway, and in 1811 some experiments were made having this object in view. At this time Timothy Hackworth was foreman of the smiths (he would now be called an engineer), and William Hedley was coal-viewer at Wylam. The friends of both Hackworth and Hedley claim for their respective heroes the honour of these early essays in locomotive construction. But it is probable the honours should be shared by both, as well as by Jonathan Foster, who also assisted in the experiments and construction of the Wylam locomotives."* After preliminary experiments the Wylam engineers constructed, in 1813, the

* Sekon, *Evolution of the Steam Locomotive*, 10.

historic locomotive "Puffing Billy," which is now exhibited in the South Kensington Museum. It had a wrought-iron boiler with a return flue, the chimney being at the same end as the fire-hold door. There were two vertical cylinders working on two large beams over the top of the boiler. The beams were connected with a crank underneath the boiler which communicated the motion by teethed-gearing to four wheels of equal diameter working by adhesion to the rails. In 1815 Hedley constructed locomotives on the same principle having eight wheels geared together, and using a steam pressure of 50 pounds per square inch, which was the steam pressure used in the locomotive constructed by Trevithick and Murray.

The story of the English railways must now be linked up with the contribution made by Stephenson. George Stephenson, the second child of six, was born in a cottage in the colliery village of Wylam on June 9, 1781. His father, Robert Stephenson, was employed as fireman of the old pumping engine at the Wylam Colliery. In front of the rude cottage in which the Stephensons lived passed the wooden waggon-way or tram-road, over which horses pulled the small waggons of coal from the colliery, and on which Blackett's engine was, in later years, run. It was here that George Stephenson, charged with the responsibility of keeping his younger brothers and sisters off the track when coal-trucks were passing, had his first introduction to that branch of engineering with which his life's work was ultimately to be associated. Robert Stephenson's scant wages were too small to allow him to pay even the small fees required by the local school, with the result that George, as a boy, could neither read nor write. When, later, the father moved to the Dewley Burn Colliery, young George obtained, after some preliminary employment, his first real position as driver of the gin-horse at the Dewley Burn Colliery. The gin-horse travelled in a circular track and revolved a drum placed horizontally round which the ropes attached to the colliery buckets revolved. The buckets were thus drawn up and sent down the shafts. Stephenson had set his mind upon becoming an engine-man, which was the most highly paid position about the colliery. The first step towards his desired goal was taken when he was accepted as assistant to his father

in firing the engine at Dewley. At fourteen years of age he was appointed assistant fireman, at the wage of 1s. per day. Stephenson's youthful triumph was achieved three years later when at a new pit at Water-row, near Wylam, on the River Tyne, he was appointed engine-man of a pumping engine erected by Robert Hawthorne, the Duke of Northumberland's engineer. His father was appointed fireman of the same engine, and thus at this early age George had succeeded in attaining to a position of responsibility greater than that occupied by his father. He now realized that the road to further progress was made more difficult on account of his own inability to read or write. He had been told that the engines of Boulton and Watt were fully described in certain books. These were as closed doors to him, for he had not the key of knowledge which opened them. With remarkable application, therefore, we find George Stephenson taking lessons from the local school teacher during three evenings per week, for which he paid the sum of 4d. per week in fees. Stephenson took every opportunity of thoroughly understanding the method of working his engine and fitting together its parts. Stephenson was next employed as brakesman at the Dolly Pit, Callerton, and a few years later he obtained at an increased wage a similar position at the West Moor Colliery, Killingsworth, a small colliery village seven miles north of Newcastle. It was the function of the brakesman to control the working of the engine and other mechanism by which coal was drawn out of the pit. Duties were rather monotonous, and especially when on night work Stephenson had considerable time on his hands, during which he was free to apply himself as he wished, and chose to mend shoes so that he could add to his slender income of £1 per week as brakesman.

While employed at Killingsworth he accepted an invitation to supervise the working of a Boulton and Watt engine at a spinning works near Montrose, Scotland, and there had an opportunity of introducing several improvements in the working of the pumps used for pumping from a well the water required to generate steam for his engine. On his return from Scotland he resumed his old position at Killingsworth, and in 1810 a Newcomen engine made by Smeaton was installed at a new

pit that had been sunk. Considerable difficulty was experienced by the builders in setting the engine to work, and after all their efforts had failed a final appeal was made to Stephenson. His efforts met with characteristic success, and he soon acquired the reputation of becoming an "engine-doctor," and was consulted by owners of engines for miles around. While Blackett was solving some of the difficult problems arising in the course of his experiments with the locomotive at Wylam, Stephenson, at Killingsworth, was turning over in his mind the same problem of a successful locomotive. Stephenson wisely made himself thoroughly familiar with all that had been done by experimenters before him, and thus availed himself of the results of their experience. Frequently he visited his birthplace, Wylam, and closely studied the work of Blackett. Indeed, it was a sore point with Hackworth that while he spent his Sundays in religious duties, Stephenson was occupied in taking sketches of the locomotives at work on the Wylam railway. An efficient and economical working locomotive, therefore, still remained to be invented, and to accomplish this object Stephenson applied himself. Profiting by what his predecessors had done, warned by their failures and encouraged by their partial successes, he commenced his labours. There was still wanting the man who should accomplish for the locomotive what James Watt had done for the steam engine, and combine in a complete form the best points in the separate plans of others, embodying with them such original inventions and adaptations of his own as to entitle him to the merit of inventing the working locomotive, in the same manner as James Watt is to be regarded as the inventor of the working condensing-engine. This was the great work upon which George Stephenson entered, though probably without an adequate idea of the ultimate importance of his labours to society and civilization.

Stephenson's first locomotive, popularly called "Blücher," was completed after much labour on the part of the inventor himself, skilled assistance being almost non-existent, and ran on July 25, 1814. It was a machine formidable in appearance, although only able to attain a maximum speed of 4 miles per hour. Its coal consumption was heavy, and it was doubtful

whether it was more economical to adopt the locomotive or continue to employ horses. After twelve months the locomotive was found to be more expensive than the horses it replaced. But a new idea occurred to Stephenson—the chimney blast, whereby the steam after performing work in the cylinder was ejected through a pipe in the boiler chimney, causing a suction draught through the furnace, and stimulating combustion. The chimney blast definitely established the locomotive, for it doubled the power of the engine. Several engines were then constructed by Stephenson, and each embodied new features that secured additional advantages, and by 1822 no fewer than five of his locomotives were running on the railroads of the Hetton Railway, in the county of Durham. This adoption of the early Stephenson locomotives may appear to be an indication of their successful operation. Although it would be incorrect to assert that the Killingsworth and Hetton locomotives were not successful, yet they did not realize the advantages which their inventor claimed for them. Galloway,* who made an exhaustive study of the early locomotives, wrote: "These locomotive engines have been long in use in Killingsworth Colliery, near Newcastle, and at Hetton Colliery on the Wear, so that their advantages and defects have been sufficiently submitted to the test of experiment; and it appears that, notwithstanding the great exertions on the part of the inventor, Mr. Stephenson, to bring them into use on the different railroads, now either constructing or in agitation, it has been the opinion of several able engineers that they do not possess those advantages which the inventor has anticipated; indeed, there cannot be a better proof of the doubt ascertained regarding their utility than the fact that it has been determined that no locomotive engine shall be used on the projected railroad between Newcastle and Carlisle, since, had their advantages been very apparent, the persons living immediately on the spot in which they are used—namely, Newcastle—would be acquainted therewith. The principal objections seem to be the difficulty of surmounting even the slightest ascent, for it has been found that a rise of only one-eighth of an inch in a yard, or of eighteen feet in a mile, retards the speed of one

* Galloway, *History of the Steam Engine*, 320.

of these engines in a very great degree, so much so, indeed, that it has been considered necessary in some parts where used, to aid their ascent with their load, by fixed engines, which drag them forward by means of ropes coiling round a drum. The spring steam cylinders below the boiler were found very defective, for in the ascending stroke of the working piston they were forced inwards by the connecting-rod pulling at the wheel and turning it round, and in the descending stroke the same pistons were forced as much outwards. This motion or play rendered it necessary to increase the length of the working cylinder as much as there was play in the lower ones, to avoid the danger of breaking or seriously injuring the top and bottom of the former by the striking of the piston when it was forced too much."

The next important step in the development of English railways was taken by Edward Pease, of Darlington, who projected the Stockton and Darlington Railway. Rich mineral deposits lay in the country surrounding Darlington, and although much of this was being worked in the early part of the nineteenth century, much more remained untouched, largely by reason of the poor transport facilities then available for conveying the coal to the east coast. "Stockton was the port from which the mineral wealth of the Durham coalfield was shipped, but owing to the winding of the River Tees, the time taken to sail from Stockton to the mouth of the river was often as long as that required to journey from London to the Tees."* As early as 1810 steps were taken to shorten the river channel, and in that year the distance was reduced by 2 miles by cutting a channel at Portrack, near Stockton. Moreover, the roads were poor and horse transport slow and costly. A committee reported in 1811 on the advantages to be derived from the construction of either a railway or canal from Stockton to Winston, via Darlington, although for some years opinion was divided as to whether a canal or railway would be most suitable. This diversity of opinion "is not to be wondered at, for up to that time no locomotive had been made that could attain a greater speed than four or five miles an hour, whereas steam navigation had many years before

* Pease, *Diaries of Edward Pease*, 83.

reached the rate of seven miles per hour. Apparently, therefore, the railway offered no advantage over a canal in the matter of speed. Nor was there yet any widespread or generally accepted idea in favour of making railways take the place of the stage coach for passenger travel. In the public mind, railways seemed to be designed chiefly for the better and faster carriage of minerals and goods, and only a few saw the latent possibilities in the locomotive engine."* The subject lay dormant until 1818, when it was actively revived by Pease, who promoted a company for surveying and constructing a railway. A Bill brought before Parliament to obtain sanction for the construction of the railway met with such bitter opposition, especially from some of the landowners through whose holdings the proposed line was to run, that it was defeated. A second application made to Parliament was successful, and resulted in the passing of the Stockton and Darlington Railway Act on April 19, 1821.

The idea of using anything but horses for motive power had not occurred to the promoters, for the Act provided that the company " should appoint their roads and ways convenient for the hauling or drawing of waggons, and other carriages passing upon the said railways or tramroads, the tramroad to be worked with men or horses, or otherwise." During certain hours of the day the public were to be free to use the railway for the conveyance of carriages and waggons, upon the payment of the company's normal rates; the gauge of the railway, 4 feet 8½ inches, was taken from the width of the road waggons. Meanwhile Stephenson, at his home at Killingsworth, had been following with interest the development of the Darlington Company, and resolved to recommend the adoption of locomotives as motive power. In company with Nicholas Wood, the viewer at Killingsworth, he visited Pease at his home in Darlington, and advocated the adoption of steam locomotives. Pease was impressed by the engineer-inventor; he later said of Stephenson: " There is such an honest sensible look about him, and he seemed so modest and unpretending. He spoke in the strong Northumbrian dialect of his district, and described himself as 'only the engine-wright at Killingsworth; that's

* Jackman, *Transportation in Modern England*, 477.

what he was.' "* As a result of this interview and subsequent enquiry respecting his work, Stephenson was invited to re-survey the proposed line, which offer he readily accepted. While the survey was in progress Pease visited Killingsworth to inspect Stephenson's locomotives and witness their performance, and returned converted as to their usefulness, so that it was not long before Parliamentary powers were obtained for working the Darlington line by steam locomotives. After this clause had been inserted in an amended Stockton and Darlington Railway Act of 1823, Stephenson was appointed engineer to the railway at a salary of £300 per annum. He worked daily on the survey of the line and personally took almost every reading of the level. "He started very early—dressed in a blue-tailed coat, breeches, and top-boots—and surveyed until dusk. He was not at any time particular as to his living; and during the surveying he took his chance of getting a little milk and bread at some cottager's house along the line, or occasionally joined in a homely dinner at some neighbouring farmhouse. The country people were accustomed to give him a hearty welcome when he appeared at their door; for he was always full of cheery and homely talk, and when there were children about the house, he had plenty of humorous talk for them as well as for the seniors."†

After much persuasion the railway directors agreed to place an order with Stephenson for the construction of three trial locomotives, the performance of which would determine the type of motive power to be adopted on the line. It was during the construction of these engines that George Stephenson, taking a tour of inspection of the work in company with his son Robert and John Dixon, said: "Now lads, I venture to tell you that I think you will live to see the day when railways will supersede almost every other method of conveyance in this country—when mail-coaches will go by railway and railroads will become the great highway for the King and all his subjects. The time is coming when it will be cheaper for a working man to travel upon a railway than to walk on foot. I know there are great and almost unsurmountable difficulties to be en-

* Quoted by Smiles, *George and Robert Stephenson*, 151.
† *Ibid.*, 156.

countered; but what I have said will come to pass as sure as you live. I only wish that I may live to see the day, though that I can scarcely hope for, as I know how slow all human progress is, and with what difficulty I have been able to get the locomotive thus far adopted, notwithstanding my more than ten years' successful experiment at Killingsworth."* As indicative of the modest expectations of the locomotive's performance, the following words of Nicholas, a recognized railway expert of that day, may be quoted: "It is far from my wish to promulgate to the world that the ridiculous expectations or other professions of the enthusiastic specialist will be realized, and that we shall see them travelling at the rate of twelve, sixteen, eighteen or twenty miles an hour. Nothing could do more harm towards their adoption or general improvements than the promulgation of such nonsense."†

The Stockton and Darlington Railway was opened on September 27, 1825, and excited wide interest and admiration. The local press representative of the day wrote: "The signal being given the engine started off with this immense train of carriages; and such was its velocity, that in some parts the speed was frequently 12 miles an hour."‡ It was shown that on an incline one engine could draw an 80-ton train at the rate of 10 to 15 miles per hour. The locomotive constructed by Stephenson, and marked "Locomotion," weighed 7 tons, and was provided with only one flue, 10 inches in diameter and 10 feet long, and so little heat was withdrawn from the products of combustion that the chimney became red-hot soon after the engine commenced working. The "Locomotion" was constructed at the Forth Street Works of Robert Stephenson and Co., at Newcastle-on-Tyne, at a time when the Forth Street works, which were later to be world-famous, were nothing more or less than smith forges. Timothy Hackworth§ was appointed manager of these works, and consequently had a good deal to do with the construction of the locomotive, which worked on the Stockton and Darlington Railway until 1850, when it was used as a pumping engine by Pease at his West

* *Ibid.*, 162.
† Jeans, *Jubilee Memorial of the Railway System*, 66.
‡ Quoted by Smiles, *op. cit.*, 164.
§ See above, p. 117.

Collieries, South Durham, until 1857; it was finally mounted on a pedestal at North Road Station, Darlington.

In June, 1825, Hackworth was appointed engineer to the Stockton and Darlington Railway, with which he maintained his connection for over fifteen years. He soon had an opportunity of turning to practical account his knowledge of locomotive building. During the year 1826 Robert Stephenson and Co. had supplied three more engines, named "Hope," "Black Diamond," and "Diligence," to the Stockton and Darlington Railway, but these engines failed to give the result that was anticipated. They were frequently stopped by a strong wind, and the horse-drawn trains on the lines were delayed because the locomotive-drawn trains could not proceed fast enough. After eighteen months' working of the line locomotives proved to be more expensive than horse-drawn trains; indeed, for equal work locomotives cost about three times as much as horse-power. The value of the Stockton and Darlington Railway stock fell rapidly, and the directors convened a meeting to decide whether locomotives should be continued. Hackworth, in his capacity of engineer and manager, said at the meeting: "Gentlemen, if you will allow me to make you an engine in my own way, I will engage that it will answer your purpose." It was agreed that "as a last experiment Timothy shall be allowed to carry out his plan." The result was the building of the "Royal George," which proved to be a really successful engine. It was tried in September, 1827, and undertook regular duties on the line in November of the same year. "During 1828, it conveyed 22,422 tons of coal over 20 miles at the rate of ¼d. a ton per mile. The cost of this, including all charges, was £466, where, according to the *Practical Mechanics' Journal*, horses for the same work cost £998."* It is of interest to observe that, when the directors of the Liverpool and Manchester Railway were considering the relative advantages of stationary and locomotive engines in connection with their own line, Stephenson supported the claims of the locomotive engine by citing the performance of the "Royal George," and the committee

* R. Young, "Timothy Hackworth and the Locomotive," in *Engineer*, CXXXIII. 251.

appointed by the directors to investigate the problem reported (March, 1829) that "Hackworth's engine is undoubtedly the most powerful that has yet been made, as the amount of tons conveyed by it, compared with other engines, proves. Its consumption of coal per ton of goods conveyed one mile, at the rate of 11 miles per hour, was 1·60 lb.; Blenkinsop's engine, at 4 miles per hour, 2·75 lb.; Killingworth and Hetton engines, at 4 miles per hour, 2·25 lb."* Although primarily intended as a goods line, the experiment of passenger conveyance was tried on the Stockton and Darlington Railway on October 10, 1825, a fortnight after the opening of the line. The specially designed coach, more like a modern pantechnicon than a present-day railway coach, drawn by one horse, covered the distance of 12 miles between the two towns in two hours, a charge of 1s. per passenger being made This coach, called the "Experimenter," continued to run daily. As an example of the improved conditions for passenger traffic we find in 1849 that "the first-class passenger is accommodated with a spacious carriage, in which usually a separate seat is divided off for each passenger, the interior being luxuriously cushioned, lined and carpeted. Convenient means of varying the ventilation at the will of the passenger are provided over the windows. A lamp is placed, in some of the best conducted railways, in the centre of the roof, with a reflector projecting the light through tunnels and at night. In some railways also a heater is placed in cold weather in first-class carriages under the feet of the passengers, and other accommodations of minor importance are provided."† An interesting comparison of relative times of transit may be quoted: "In 1678 a contract was made to establish a coach for passengers between Edinboro' and Glasgow, a distance of 44 miles. This coach was drawn by six horses and the journey between the two places, to and from, was completed in six days. Even so recently as the year 1750 the stage coach from Edinboro' to Glasgow took 36 hours, and in the year 1849 the same journey is made by a route three miles longer in one hour and a half!"* It is note-

* R. Young "Timothy Hackworth and the Locomotive," in *Engineer*, CXXXIII. 251.

† Lardner, *Railway Economy*, 85.

worthy that between 1849 and 1923 the railway journey has only been shortened by twenty-five minutes, as the present fastest scheduled expresses take sixty-five minutes for the journey.

One noteworthy result of the Stockton and Darlington Railway was the creation of the town of Middlesbrough. "When the railway was opened in 1825, the site of this future metropolis of Cleveland was occupied by one solitary farmhouse and its out-buildings. All round was pasture land or mud-banks; scarcely another house within sight. In 1829 some of the principal proprietors of the railway joined in the purchase of about 500 or 600 acres of land five miles below Stockton—the site of the modern Middlesbrough—for the purpose of there forming a new seaport for the shipment of coals brought to the Tees by the railway. The line was accordingly extended thither; docks were excavated; a town sprang up; churches, chapels, and schools were built, with a customs house, mechanics' institute, banks, ship-building yards, and iron factories. In ten years a busy population of some 6,000 persons occupied the site of the original farmhouse. Middlesbrough does not furnish the only instance of the extraordinary increase of population in certain localities, occasioned by railways. Hartlepool, in the same neighbourhood, has in thirty years increased from 1330 to above 15,000; and Stockton-on-Tees, from 1,763 to above 16,000. In 1831 Crewe was a little village with 295 inhabitants; it now numbers upwards of 10,000. Rugby and Swindon have quadrupled their population in the same time. The railway has been the making of Southampton, and added 30,000 to its formerly small number of inhabitants. In like manner the railway has taken London to the seaside, and increased the population of Brighton from 40,000 to nearly 100,000. That of Folkestone has been trebled. New and populous suburbs have sprung up all round London. The population of Stratford-le-Bow and West Ham was 11,580 in 1831; it is now nearly 40,000. Reigate has been trebled in size, and Redhill has been created by the railway. Blackheath, Forest Hill, Sydenham, New Cross, Wimbledon, and a number of populous places round London, may almost be said

* *Ibid.*, 32.

to have sprung into existence since the extension of railways to them within the last thirty years. More recently the discovery of vast stores of ironstone in the Cleveland Hills, closely adjoining Middlesbrough, has tended still more rapidly to augment the population and increase the commercial importance of the place."*

The successful operation of the Stockton and Darlington line stimulated the commercial acumen of business promoters in Manchester and Liverpool to form a company for the surveying and construction of a line to join these two stations. The tendency of the growing cotton industry in South Lancashire gradually to centre round Manchester made it necessary for easy communication with Liverpool to be established both for the distribution of sea-borne raw cotton and for exporting purposes. The Bridgewater Canal had eased the situation somewhat, but the slow method of road transport and the restricted possibilities of the canal were felt to be inadequate to meet the growing demands for convenient intercommunication. Sanders, a Liverpool merchant, did for the Liverpool and Manchester Railway what Pease achieved for the Stockton and Darlington line, and acted as promoter of the scheme. A preliminary survey of the line was undertaken amid considerable difficulties; the natives of the country-side received the survey party with great hostility, and on many occasions broke their instruments and roughly handled their persons. William James, of West Bromwich, a promoter of railways and a colleague of Sanders, was in charge of the survey, and he had heard of Stephenson's work in connection with locomotive development in the North of England. After the initial survey had been completed, therefore, he resolved to inspect the products of Stephenson's skill and genius, that he might be better able to consider their application to the proposed Lancashire line. He was well satisfied with his visit to Killingsworth, and returned convinced of the power and efficiency of Stephenson's locomotive. Owing to discrepancies in the preliminary survey of the Liverpool to Manchester line, a second survey was ordered, which was again supervised by James, who this time was assisted by Robert Stephenson. The diffi-

* Smiles, *op. cit.*, 173. This passage was written in 1862.

culties were so overwhelming that James finally gave up the attempt, and the projectors of the scheme were compelled to call in other aid. Following James's visit to Killingsworth, Sanders had visited George Stephenson and was equally impressed with his ability and personality, with the result that George Stephenson was unanimously appointed engineer by the committee concerned with the projection of the line. After wide publicity had been given to the scheme in Liverpool and Manchester, a prospectus of the company was drawn up on October 29, 1824, setting forth the main advantages of the proposed line, that it would reduce the time of transport of goods between the two towns to five or six hours instead of the thirty-six hours that were then occupied on the canal. At the same time it was suggested that the cost would be reduced by one-third.

Numerous difficulties were met with,* particularly organized opposition on the part of the canal companies. Smiles describes in the following manner the form which the campaign of the canal companies took: "The public were appealed to on the subject; pamphlets were written and newspapers were hired to revile the railway. It was declared that its formation would prevent cows grazing and hens laying. The poisoned

* The public press contained outbursts of indignation at the encroachment of the locomotives. As typical of the letters that daily appeared in the press, the following two examples are quoted. A letter from "No Railer at the Present System" in the *Birmingham Gazette*, January 10, 1825, ends by saying: "Do, good Mr. Editor, lend your potent aid, at the commencement of the coming year, to avert this mass of evils, and help by advice, by entreaty, by warnings, by ridicule, by anything, to thwart the designs of these iron-hearted speculators who would take from the people of this free country all hopes of another Merry Christmas. If we must be slaves let it not be to iron-masters—let us open our eyes before the accumulation of smoke renders it impossible for us to see, and let us, above all things, beware lest Railroads, like party, prove 'the madness of many for the gain of few.'" A letter in the *Leeds Intelligencer*, January 13, 1825, signed by "Ebenezer," evidently a Quaker, says: "On the very line of this railway, I have built a comfortable house; it enjoys a pleasing view of the country. Now judge, my friend, of the mortification, whilst I am sitting comfortably at breakfast with my family, enjoying the purity of the summer air, in a moment my dwelling, once consecrated to peace and retirement, is filled with dense smoke or fœtid gas; my homely, though cleanly, table covered with dirt, and the features of my wife and family almost obscured by a polluted atmosphere. Nothing is heard but the clanking iron, the blasphemous song, or the appalling curses of the directors of these infernal machines."—Jackman, *op. cit.*, 497.

air from the locomotives would kill the birds as they flew over them, and render the preservation of pheasants and foxes no longer possible. Householders adjoining the projected line were told that their houses would be burnt up by the fire thrown from the engine chimneys; while the air round would be polluted by clouds of smoke. There would no longer be any use for horses; and if railways extended, the species would become extinguished, and oats and hay be rendered unsaleable commodities. Travelling by rail would be highly dangerous and country inns would be ruined. Boilers would burst and blow passengers to atoms. But there was always this consolation to wind up with—that the weight of the locomotive would completely prevent its moving, and that railways, even if made, could never be worked by steam power."* The Bill came before the House of Commons in March, 1825, but the evidence brought forward by the opponents to the railway was so strong that upon the first two clauses being defeated, the Bill was withdrawn. Mr. Harrison was leading counsel for the canal proprietors, and the tenor of his speech before the House of Commons Committee is indicative of the general ignorance that then prevailed respecting the function of the steam locomotive. During the course of his closing speech, the following observations occur: "To make the thing popular a certain number of ingenious gentlemen were set to write pamphlets. . . . All the pamphlets published about it gave us 12 miles per hour as the rate at which they were to go; you were to gallop from Liverpool to Manchester at the rate at which mail-coaches have tried to go, but never accomplished. . . . But, not content with goods, they are to take passengers. Now, set them off with horses before them; set the proprietor of the railway travelling on their own road, from Liverpool to Manchester in waggons at the rate of 4 miles per hour; it is impossible to state it without presenting something ludicrous to the mind!"†

While this gives an idea of the attitude of the public towards railways at the commencement of the nineteenth century, we find a similar attitude expressed in 1849 to the running of

* Smiles, *op. cit.*, III. 195.
† Quoted by Baines, *History of Liverpool*, 596, 597.

express trains, both from the point of view of danger and expense. The view was held that they should be reduced or even abolished, on the grounds that both directly and indirectly they were a source of vast expense: directly, in that their extreme speed caused considerable deterioration of the rails, engines, and vehicles of transport; and indirectly, by causing, through the stoppages of local trains, additional wear and tear.

Among the list of rules for railway travellers in 1849 we find Rule VII.: "Express trains are attended with more danger than ordinary trains. Those who desire the greatest security should only use them when great speed is required."*

Despite Parliament's rejection of the Bill, the directors of the company were determined at all costs to push ahead with the scheme, and to use horses as the tractive power rather than abandon the scheme altogether. At this time George Stephenson was ignored, and George and John Rennie appointed as engineers to the railway. With slight alterations the original proposals of Stephenson were in general adopted, and after the new survey had been carried out, a fresh Bill was prepared for presentation to Parliament. On this occasion the Bill was passed and the way left clear for the construction of the railway. The brothers Rennie were not prepared to accept the conditions laid down by the directors, and George Stephenson was again appointed principal engineer of the railway. The first problem he attacked was that of constructing a road over Chat Moss, which has been described as an almost impassable bog, 12 miles square in area, approximately midway between Liverpool and Manchester. Stephenson conceived the idea of literally floating a road across the bog. The base of the road was constructed by means of loose turf and bundles of ling or heather, over which was spread some fine gravel, on which, finally, the railway sleepers were laid in the ordinary way. The road across Chat Moss was finished by January 1, 1830, on which day the first experimental train, drawn by Stephenson's locomotive the "Rocket," passed over this part of the road. It ultimately became one of the best sections, and owing to the floating character of the road, shock on the train was greatly reduced due to the springiness. The first extensive piece of stone-

* Lardner, *Railway Economy*, 260, 269, 339.

cutting which took place on the railway systems of this country was carried out on the Liverpool end of the line, where the cutting, 2 miles long, and in many parts 80 feet deep, known as "Olive Mount Cutting," was hewn out of the solid rock, as much as 48,000 cubic yards of stone being removed.

Although the construction of the line commenced in 1826, the type of tractive power to be used on the line had not been decided upon even as late as 1828. Stephenson strongly advocated the adoption of steam power, whereas there were numerous and influential persons in favour of horse transport. Steam was a new power, and the public were naturally conservative regarding its adoption. In fact, in 1829, the Government first passed the Newcastle and Carlisle Railway Act, only on the understanding that horses were to be used. Stephenson persuaded the directors to permit him to build a trial locomotive, to be used in the construction of the line for drawing trucks, etc. He produced the historic "Rocket," which to-day stands in the Victoria and Albert Museum, South Kensington, and which, as has been already noted, drew the first experimental train over Chat Moss. Gradually the idea of steam as tractive power became acceptable to the directors, but the problem still remained unsolved as to whether the engines should be locomotives or stationary. It was proposed by Booth that the line between Liverpool and Manchester should be divided into nineteen stages of about a mile and a half each, with twenty-one engines fixed at different points to work the trains forward. In order to test the possibilities of the locomotive, the directors of the company offered a prize of £500 for the locomotive which would best carry out, on a certain day, a prescribed performance under definite conditions. These conditions were laid down in the following document:

"RAILWAY OFFICE, LIVERPOOL,
"*April* 25, 1829.

"STIPULATIONS AND CONDITIONS ON WHICH THE DIRECTORS OF THE LIVERPOOL AND MANCHESTER RAILWAY OFFER A PREMIUM OF £500 FOR THE MOST IMPROVED LOCOMOTIVE ENGINE.

"1. The said engine must effectually consume its own smoke, according to the provisions of the Railway Act, 7th George IV.

"2. The engine, if it weighs six tons, must be capable of drawing after it, day by day, on a well constructed railway on a level plane, a train of carriages of the gross weight of twenty tons, including the tender and water-tank, at the rate of ten miles an hour, with a pressure of steam in the boiler not exceeding 50 lbs. on the square inch.

"3. There must be two safety valves, one of which must be completely out of reach or control of the engine-man, and neither of which must be fastened down while the engine is working.

"4. The engine and boiler must be supported on springs and rest on six wheels, and the height from the ground to the top of the chimney must not exceed 15 feet.

"5. The weight of the machine with its complement of water in the boiler must, at most, not exceed six tons, and a machine of less weight will be preferred, if it draw after it a proportionate weight, and if the weight of the engine, &c., does not exceed five tons, then the gross weight to be drawn need not exceed fifteen tons, and in that proportion for machines of still smaller weight; provided that the engine, &c., shall still be on six wheels, unless the weight (as above) be reduced to 4½ tons or under, in which case the boiler, &c., may be placed on four wheels. And the Company shall be at liberty to put the boiler, fire-tube, cylinders, &c., to the test of a pressure of water not exceeding 150 lbs. per square inch, without being answerable for any damage the machine may receive in consequence.

"6. There must be a mercurial gauge affixed to the machine with index rod, showing the steam pressure above 45 lbs. per square inch, and constructed to blow off at a pressure of 60 lbs. per square inch.

"7. The engine to be delivered complete for a trial at the Liverpool end of the railway, not later than the 1st October next.

"8. The price of the engine which may be accepted not to exceed £550, delivered on the railway, and any engine not approved to be taken back by the owner.

"*N.B.*—The Railway Company will provide the engine tender with a supply of water and fuel for the experiment. The distance between the rails is 4 feet 8½ inches."

Immediately before the trial the judges issued the following instruction:

"TRIAL OF THE LOCOMOTIVE ENGINES ON THE LIVERPOOL AND MANCHESTER RAILWAY.

"The following is the ordeal which we have decided each locomotive shall undergo in contending for the premium of £500 at Rainhill.

"The weight of the locomotive engine with its full complement of water in the boiler, shall be ascertained at the weighing machine by 8 o'clock in the morning, and the load assigned to it shall be three times the weight thereof. The water in the boiler shall be cold, and there shall be no fuel in the fire-place. As much fuel shall be weighed, and as much water shall be measured and delivered into the tender-carriage as the owner of the engine may consider sufficient for the supply of the engine for a journey of thirty-five miles. The fire in the boiler shall then be lighted, and the quantity of fuel consumed for getting up the steam shall be determined, and the time noted.

"The tender carriage, with the fuel and water, shall be considered to be, and taken as part of, the load assigned to the engine.

"Those engines which carry their own fuel and water shall be allowed a proportionate deduction from their load, according to the weight of the engine.

"The engine, with the carriage attached to it, shall be run by hand up to the starting post, and as soon as the steam is got up 50 lbs. per square inch, the engine shall set out upon its journey.

"The distance the engine shall perform each trip shall be one and three-quarter miles each way, including an eighth of a mile at each end, one for getting up the speed and the other for stopping the train; by this means the engine with its load will travel one and a half miles each way at full speed.

"The engine shall make twenty trips, which shall be equal to a journey of thirty-five miles, thirty miles whereof shall be performed at full speed, and the average rate of travelling shall not be less than ten miles an hour.

"As soon as the engine has performed this task, (which shall be equal to the travelling from Liverpool to Manchester), there shall be a fresh supply of fuel and water delivered to her, and as soon as she can be got ready to set out again, she shall go up to the starting post and make twenty trips more, which will be equal to the journey from Manchester back again to Liverpool.

"The time of performing every trip shall be accurately noted, as well as the time occupied in getting ready to set out on the second journey.

"Should the engine not be enabled to take along with it sufficient fuel and water for the journey of twenty trips, the time occupied in taking in a fresh supply of fuel and water shall be considered and taken as a part of the time in performing the journey.

"J. W. RASTRICK, C.E., Stourbridge
"NICHOLAS WOOD, C.E., Killingsworth } *Judges.*
"JOHN KENNEDY, Manchester

"LIVERPOOL,
"*October* 6, 1829."

The competition was arranged to commence on October 6, 1829, and on the result depended the decision as to the motive power to be used for working the Liverpool and Manchester Railway. Five competitors entered the field:

No. 1. Braithwaite and Ericsson, of London.
The "Novelty": weight, 2 tons 15 cwt.
No. 2. Timothy Hackworth, of Darlington.
The "Sanspareil": weight, 4 tons 6 cwt. 2 qrs.
No. 3. Robert Stephenson, of Newcastle-upon-Tyne.
The "Rocket,": weight 4 tons 3 cwt.
No. 4. Brandrith, of Liverpool.
The "Cyclope": weight, 3 tons, worked by a horse.
No. 5. Burstall, of Edinburgh.
The "Perseverence": weight, 2 tons 17 cwt.

Only four of the locomotives were in the track ready to take part. The "Cyclope" was disqualified as it did not fulfil the conditions of the competition, a horse providing the motive power. Although Stephenson's engine did not appear first on the list, it was the first ready for trial, and was therefore called first. The "Novelty" was the second to be called, then the "Sanspareil," and lastly the "Perseverence." The "Rocket" was the only one which satisfied, and more than satisfied, the conditions of the trial. Dispute arose over the load to be drawn by the "Novelty," and it did not go beyond the stage of being merely exhibited. Although the "Sanspareil" was not ready until October 13, its cold-water pump became disordered on the eighth trip and the engine stopped. The "Perseverence" was found unable to attain more than 5 or 6 miles an hour, and it was early withdrawn from the contest. Finally the "Rocket" was declared to be fully

entitled to the prize of £500, and after the award Stephenson brought his locomotive on to the track and ran it himself, when it was found to be able to attain the speed of 35 miles an hour. This excellent performance secured for the locomotive an unassailable position, and it was decided to adopt this type of tractive power for the Liverpool and Manchester line. The railway was completed and ready for the trial run on June 14, 1830, when the first trip was undertaken, the train being drawn by the locomotive "Arrow," operated by Stephenson himself. Everything went successfully, and the outward journey was achieved at the average rate of 17 miles per hour. The return journey in the evening was accomplished in an hour and a half. The public opening of the line took place on September 15, 1830, and a great concourse of people assembled to witness the ceremony. Many persons of public note were present, including the Duke of Wellington, then Prime Minister, Sir Robert Peel, and Mr. Huskisson. An unfortunate accident occurred during that day, Mr. Huskisson being knocked over by the "Rocket" and receiving injuries from which he died shortly afterwards. On the following morning the railway was opened for public traffic, the allotted time of the journey being two hours, which was regularly maintained.

Stephenson continued to devote himself to the problem of improving the construction of the locomotive to secure efficient and regular performance. In the "Planet," which had been placed on the Liverpool to Manchester line immediately after its public opening, Stephenson introduced all improvements in locomotive design which he had up to that time contrived. The engine traversed the distance from Liverpool to Manchester with a load of 80 tons in nine and a half hours, despite a strong head wind. The "Planet" was followed in the next year by the "Samson," which embodied the important improvement of coupling the front and rear wheels, whereby greater adhesion of the wheels to the rails was secured. The "Samson" succeeded in drawing a load of 150 tons at a speed of about 20 miles an hour, the coke consumption being only about ⅜ pound per ton per mile. The success of the Liverpool to Manchester line was so distinct that numerous other projects quickly followed, in each one of which Stephenson's aid was sought. A line

from Liverpool to Birmingham was first projected in 1824, and was later modified, under the name of the Grand Junction Railway, to be a continuation of the Liverpool to Manchester line, from Newton, through Warrington to Birmingham. On two occasions the Bill was defeated, owing mainly to the opposition of the adjacent landowners, but the Act was finally passed in 1833. The next most important line constructed by Stephenson was the London and Birmingham Railway, completed in February, 1838. Numerous other railways constructed by Stephenson were opened about this time, and included Sheffield to Rotherham, Crewe to Birkenhead, Manchester to Birmingham, and Manchester to Leeds.

One of the principal claims of railway projectors was that the cost of carriage would be greatly reduced, and thus confer benefits on both consumers and producers. During the winter months the canals were frequently frozen for long periods, and at such times the cost of coal, both for domestic and manufacturing purposes, rose to exorbitant prices, for canal transport had then to be temporarily replaced by the more expensive road transport. It was claimed that "to maintain and enlarge both the home and the foreign market, the articles supplied must be cheaper and better than could be produced elsewhere, and that necessitated cheaper communication and facility in executing orders. The opening up of new and larger markets would infuse a new spirit into industry as well as agriculture, and the material resources of the realm would no longer lie waste."*

Apart from George Stephenson and his son Robert, three other names stand out supreme as advocates of the railway; they are Nicholas Wood (an intimate friend of George Stephenson), Thomas Gray, and William James. Gray was a voluminous writer in the public press on the advantages of the railway system, and published a treatise on a *General Iron Railway*.† He pictured the time when the railway would be universally

* Jackman, *op. cit.*, 487.

† The full title is: "Observations on a General Iron Railway, or Land Steam Conveyance; to supersede the Necessity of Horses in all Public Vehicles; showing its vast superiority in every respect, over all the present pitiful Methods of Conveyance by Turnpike Roads, Canals, and Coaching. Containing every Species of Information relative to Railroads and Locomotive engines, 1821."

adopted for all inland transport purposes, and especially warned the public against supporting canal enterprises, "for the time is fast approaching when railways must, from their manifest superiority in every respect, supersede the necessity both of canals and turnpike roads, so far as the general commerce of the country is concerned."* William James was one of the earliest promoters of passenger transit on railways. As early as 1799 he was engaged in planning railways, and his diary† shows that by 1808 he had surveyed very many railroads. We have already noted his work in connection with the survey of the Liverpool to Manchester line. In one of his writings James claims to be an engineer of experience, "in railroads especially"; one of his plans appears to have been the formation of a company with £1,000,000 capital "to take lands for ever to form railroads." Although his capacity was recognized during his lifetime, he appears to have become obscured in history for reasons difficult to discover.

The development of railways during the first half of the nineteenth century exercised a pronounced effect upon the reduction of unemployment throughout the country. Following the Peace of 1815, distress was general. The effects of bad harvests had been intensified by one-sided legislation. After twenty years of war large numbers of men were disbanded from the army and navy, and were thrown back on the land at a time when the land could least support them. The Poor Law Amendment Act of 1834 was designed to reduce unemployment, and the Commissioners in their reports for 1835-1836 drew attention to the success of the Amendment Act in assisting the migration of agricultural families from rural employment in the east and south of England to industrial employment in the Midlands and the north. This migration, however, is more attributable to the growth of the two new industries, railway construction and coal-mining, than to Poor Law legislation. Much evidence exists of the absorption of agricultural labourers to railway construction. We learn that in 1836 in Bedfordshire and Buckinghamshire "an immense

* *Gentleman's Magazine*, XCIV., part 2, 313-316. Quoted by Jackman, *op. cit.*, 508.

† "The Two James's and Two Stephensons," in the *Mining Journal*, December 5, 1857. Quoted by Jackman, 510.

number of our labourers are employed on the railway."* A farmer from the adjacent county of Berkshire reported that, "from the great call there is for labour in the railways and other undertakings at present we have no over-plus of labourers as we used to have—from that cause or introduction of the Poor Law."† Speaking of the London and Liverpool Railway, Mr. Joseph Sanders, a Liverpool corn merchant, in evidence before a Parliamentary Committee, stated: "I believe that there are no less than 20,000 persons employed on the railroad between London and Liverpool. . . . If the manufacturers had been in a state of distress and these railways had not been in course of erection, the conditions of the farmers' labourers must have been wretchedly bad indeed."‡

In 1845 the heaviest engines on the London and Birmingham railway did not weigh more than 12½ tons, and only one of the ninety engines then owned by that company ran on more than four wheels. The average speed of the trains was 25 miles per hour. In 1847 Mr. F. Trevithick, locomotive superintendent of the London and North-Western Railway works at Crewe, and son of the famous Cornish engineer, constructed a locomotive called the "Cornwall," embodying new features of design which are of importance in the history of locomotive engineering. "Its chief feature was that the axle of the driving wheels was above the barrel of the boiler, the idea being to keep the centre of gravity as low as possible, and thus get a large boiler area and heating surface, and at the same time ensure complete safety in running at high speeds. It was thought at this time by most locomotive engineers that a large boiler fixed in the ordinary way made the engine top-heavy, and was not compatible with safety in narrow-gauge engines running at high speeds, an argument which was always addressed in favour of the 7-foot gauge. . . . The 'Cornwall,' as originally constructed, was not a success, and it was subsequently rebuilt at Crewe, and fitted with an ordinary type of boiler above the axle."§

It was in 1847 that the "battle of the gauges" began, the

* Lords Committee on the State of Agriculture (1836), Q. 487.
† *Ibid.*, Q. 840. ‡ *Ibid.*, Qs. 4040, 4041.
§ Cooke, *British Locomotives*, 38, 39.

final issue being whether a 7-foot or 4 foot 8½ inches gauge should be adopted throughout the country. At that time, however, no uniformity existed among the railways, as the following list shows:

	Feet.	*Inches.*
Ballochney Line (Scotland)	4	6
Liverpool and Manchester, Grand Junction, London and Birmingham, and other lines built by Stephenson ..	4	8½
London and Blackwall, Eastern Counties, and Northern and Eastern lines	5	0
Dundee and Arbroath, and Arbroath and Forfar lines ..	5	6
Ulster Railway	6	0
Great Western Railway	7	0

Brunel, of the Great Western Railway, had built locomotives with 18-inch cylinders, 24-inch stroke, and 8-foot driving wheels, running on a 7-foot gauge, but until Trevithick constructed the "Cornwall," it was thought that such an engine could not be built on 4 feet 8½ inches gauge. There is but little doubt that the work of Trevithick did a good deal to influence engineers in favour of the narrower gauge. The necessity for having all rolling stock interchangeable from line to line was realized as being an essential condition to railway development. The 4 feet 8½ inches gauge was generally adopted throughout the kingdom, and in May, 1892, the last piece of 7 feet track on the Great Western line was abolished.* To-day railways in Great Britain are built to gauges other than 4 feet 8½ inches only under exceptional conditions.

A great increase in locomotive capacity has resulted from the introduction of "compounding" into locomotive design. In this country the practice originated with Mr. Webb, of the London and North-Western Railway, who in 1882 constructed the first compound locomotive, known as the "Experiment." By this invention the steam, after doing work in one cylinder or pair of cylinders, is introduced into a second and larger cylinder where the expansion of the steam is completed. If too great an expansion is carried out in one cylinder, cylinder condensation and re-evaporation result, as the cylinder walls are alternately heated and cooled. By compounding a greater

* "The last broad-gauge train to leave London was the 11·45 a.m.—'Flying Dutchman'—on May 20, 1892. The conversion of the line from broad to narrow gauge occupied thirty-one hours."—Cooke, *op. cit.*, 44.

range of expansion is obtained, which enables advantage to be taken of high-pressure steam. It must be admitted, however, that the compound working of locomotives has not realized all the advantages which its advocates originally claimed. Compounding has achieved its best results in marine and stationary engines, and the conditions of operation of such engines are essentially different from those obtaining in the locomotive. In the latter the speed of running and the amount of work done are always changing. Even when working the same train day after day, a locomotive has to meet different conditions each time. Compounding, on the other hand, is most successful on an engine which runs at constant speed and load for considerable periods. The driver is the governor of the locomotive, and his methods and personality are very important factors in the satisfactory working of the engine. He cannot be as infallible as the mechanical governor which controls the stationary engine. These considerations provide some reasons for the limited application of compounding in locomotive practice in this country. Locomotives built on this plan are not extensively used on the London and North-Western Railway, North-Eastern, and Great Eastern,* although probably the most successful compound engines in this country are the Smith three-cylinder type on the Midland Railway, the first of which was built at Derby in 1902. These engines have hauled the heaviest trains over the very difficult Leeds-Carlisle section of the line at speeds of 60·8 miles per hour on the level, and 43·1 miles per hour on a 1 in 100 gradient, 15 miles long. The advent of the superheater has arrested the progress of the compound locomotive. The principle of superheating consists of giving to the steam a temperature higher than that which would correspond to its pressure. Saturated steam—that is, steam having the temperature which corresponds to its pressure—is a very unstable fluid. It is always on the point of condensation, which will be caused by the least fall in temperature. By raising the temperature say 50 degrees, we can be sure it will cool about 50 degrees without condensation, and this is the object of superheating. Superheating does as much for the locomotive as compounding did in providing increased

* Under the grouping of railways these names have now been changed.

expansion, but with superheated steam extended expansion can be carried out in one cylinder. The subject had been investigated a long while ago, but even at present it is in a very immature state. As far back as 1845 a Great Western engine was fitted with a superheater, and in the early fifties MacConnell, on the London and North-Western Railway, also employed superheaters on some of the engines. In order to render this system efficient, a high degree of superheat is necessary. In the early stages this was not possible, as no lubricant was then available which would withstand very high temperatures. With the introduction of mineral oil lubricants able to withstand high temperatures, the development of superheaters has rapidly progressed. Various types of superheaters have within recent years been developed, in this country particularly the Swindon superheater, almost entirely confined to the Great Western Railway; the Horwich superheater on the Lancashire and Yorkshire Railway engines; and the Robinson superheater on the Great Central Railway, and also installed on several other British railways. On the North-Eastern Railway a saving of 20 per cent. in fuel on express trains, 14 per cent. on goods trains, and 10 per cent. on mineral trains is claimed as a result of superheating. The London and North-Western Railway reports an average saving of 25 per cent. of coal and a great economy in water consumption.

As regards the type of locomotive considerable diversity has hitherto existed in various lines; but the policy now adopted by nearly all the leading companies of manufacturing their own rolling stock, and the obvious advantage of having interchangeable parts, has led of late to the gradual adoption of a more uniform style of construction for the different kinds of service required. As a general rule inside cylinders are in use on the through lines of the United Kingdom, it being contended by many authorities that for high speeds the placing of the weightier parts of the machine close to the centre of gravity minimizes oscillation. It is held, further, that the moving part of the machinery is better protected by being placed within the wheels. On the other hand, the objections to be argued are the increased cost and complication of the driving axle and the comparative inaccessibility of the valves and pistons for

purpose of repair. Outside cylinders have been adopted on the London and South-Western Railway and on other lines; and supported by the bogie-truck, this form of engine approximates closely to the type in use on American railroads. The bogie-truck consists of a separate frame carried by two or more sets of wheels and attached to the engine or carriage by a central pivot; by this contrivance the wheels adapt themselves more readily to inequalities or to steep curves. The large single driving wheel at one time generally used on express locomotives is now more rare, except in the case of some of the new compound engines, but for high speeds it possesses some advantages. For goods engines the six-coupled wheel, inside cylinder type, is in most general use, while the forms of tank engines for local and suburban lines and for shunting purposes vary with the different companies and the different services to be performed. A contrivance for picking up water in transit from troughs placed between the rails, the invention of Mr. Ramsbottom, of the London and North-Western Railway, is in use on some lines where long distances are run without stopping. In the matter of fuel, some very successful experiments have been made on the Great Eastern Railway in the use of oil refuse in conjunction with coal, and liquid fuel is now employed on many of the company's locomotives. The use of liquid fuel by itself in steam locomotive work is open to some objections, such as the starting of the fires and the sudden reduction of temperature when the fuel is shut off, but those do not apply where the two fuels are interchangeable.*

There are several factors which tend to impose limiting conditions upon the present possibilities of locomotive construction. The chief is due to the loading gauge; no part of a locomotive may be more than 13 feet 6 inches above rail level, in order to clear safely bridges, tunnels, sheds, etc. The expense involved in increasing the loading gauge would be prohibitive, and it would cost at least as much to enlarge the present tunnels as to build new ones. In addition there is the restriction imposed by the spacing and arrangement of the tracks. No locomotive in this country must be wider than 9 feet. The length of the fixed wheel-base must not exceed

* Cooke, *op. cit.*, 246, 340.

a certain amount, in order that the engine may run round existing curves with safety. The total length of the wheel-base of the engine and tender is further limited to the length of the turntables which are to be found at all terminal stations and at a large number of intermediate stations and junctions. To enlarge all the turntables on a leading English railway would be a very costly business, though not outside the bounds of possibility. It is not likely to be done, however, until considerable increases in the length of the locomotive become necessary.

PART II

CHAPTER VIII

THE INFLUENCE OF PROGRESS IN IRON AND STEEL MANUFACTURE ON ENGINEERING DEVELOPMENT

IMPROVEMENTS in the manufacture of iron and steel have determined to a very considerable extent the development of engineering, especially during the past century.

Little is known of the manufacture of iron in Saxon times. At the time of the Norman Conquest the city of Gloucester was renowned for its forgings, which were made from iron obtained from the Forest of Dean, and Doomsday Book states that its payments to the King included "dicras" of iron and iron bars "suitable for ship nails."* The trade declined under the Normans, and the metal became so rare a metal that in the reign of Edward III. the iron cooking utensils of the Royal household were classed as Crown jewels. An Act passed in this reign prohibited the export of iron, under heavy penalties.

The methods of extracting the metal from the ore remained very crude for a long period. When iron ore was found the local smith converted it with the charcoal of the surrounding forests into wrought iron, which he then worked up. Many farmers had their own little forges or smithies to supply iron for their tools.† Nevertheless improvements were from time to time effected in the methods of working the finished material, and gradually the art was acquired of making swords and armour of a very high quality in iron and steel. Much of the steel used in this way was imported from the Continent, and at intervals colonies of foreign workmen settled in this country, so that the proficiency of the native smith was to some extent due to Continental influence. One German colony which settled near

* Ballard, *The Domesday Boroughs*, 78.
† *Encyclopædia Britannica*, s.v. "Iron."

Newcastle-upon-Tyne in the early part of the fifteenth century is known to have attained some celebrity in the manufacture of swords and edge tools.

After the discovery of gunpowder, the manufacture of cannon was developed. The early cannon was made of bronze, but later iron was used. The iron cannon was made in the form of a tube composed of bars arranged like the staves in a barrel and strengthened by iron bands. The usual projectiles were round stone balls; iron "gun stones" were not made until the closing years of the fifteenth century. "The life of a gun in those days seems to have been short, and that of a gunner precarious. In 1496, when the Government range was at Mile End, 13s. 4d. was given to Blase Ballard, gunner, 'towards his leche craft of his hands and face, hurt at Myles Ende by fortune shoting of a gunne,' and this is not the only hint we have that these weapons were sometimes as dangerous to their users as to the enemy."*

A notable advance was made in the fourteenth and fifteenth centuries when German metallurgists discovered the possibilities of cast iron. Up to this time iron had been converted directly from the ore into wrought iron, and sometimes into steel. The metal did not become fluid, but was obtained from the furnaces as a pasty mass which was hammered into a shape that could be readily forged. The Germans used a small blast furnace known as the "stuckofen," and by its means produced fluid cast iron. Cast iron had probably been obtained earlier by accidental means, but it was not until this period that the use of the material was recognized. The first use of cast iron in this country to be prominently noted was in 1543, when Ralph Hogge, of Bucksteed in Sussex, made a cast-iron cannon. Hogge was assisted by Peter Baude, a Frenchman, who afterwards commenced in business on his own account. Baude was succeeded by John Johnston, whose son Thomas, about the year 1595, made forty-two pieces of ordnance for the Earl of Cumberland, each piece weighing 6,000 pounds.

After the discovery of cast iron the industry grew to considerable dimensions. Iron works were usually located in a well-wooded district, where large supplies of wood were readily

* Salzman, *English Industries of the Middle Ages*, 110.

available for conversion into the charcoal that was used as fuel in the furnaces. The old hand bellows were displaced about the year 1600 by bellows driven by water power, and it then became necessary to locate the works near a running stream, though even previous to this time a site in the neighbourhood of water was generally sought for the smithy or hearth, and for the domestic use of the iron workers. The increasing demand for wood for use as fuel produced a serious effect upon the timber supply. Large tracks of forest land gradually became bare treeless country. In Sussex and the adjoining counties one entire forest, 120 miles long by 30 broad, was laid bare to provide fuel for the iron works. It became evident that, were the destruction of our forests "by voracious iron works," as Evelyn termed them, to continue unabated, fuel would gradually become unobtainable, and there would be a great shortage of timber for ship-building for the navy, and for building in general. A drastic remedy was therefore adopted. An Act of 1558 ordered that "no person or persons hereafter shall convert or employ or cause to be converted or employed to coal (*i.e.*, burn into charcoal) or other fuel for the working of iron, any timber tree or timber trees of oak, beech, or ash, or of any part thereof, of the breadth of one foot square at the stub end growing within fourteen miles of the sea, or of any part of the river of Thames, Severn, Wye, Humber, Dee, Tyne, Tees, Trent or any other river or creek or stream by which carriage commonly used by boat or other vessel to any part of the sea," under heavy penalties. "Provided always that this act shall not extend to the county of Sussex, nor to the weald of Kent, nor to any of the parishes of Charlwood, Newdgate, and Leigh, in the weald of the county of Surrey."* But the Act failed to prevent the destruction of much valuable woodland.† By 1640, owing to the scarcity of charcoal for smelting purposes and the subsequent shutting down of furnaces, the annual production of iron had fallen enormously. Much timber had been saved, but the iron trade had received a blow from which it did not recover for a century.

* 1 Elizabeth, c. 15.

† In 1586 another Act was passed extending the restrictions to the places excepted under the former Acts and prohibiting the erection of new works (27 Elizabeth, c. 19).

Attention was now directed to the possibility of using an alternative fuel, and several attempts were made to employ pit coal or " sea coal," as it was called, in the smelting of iron. One of the principal difficulties was the caking property of the coal, which caused it to cohere as one mass and restricted the passage of gas through the furnace. Another difficulty was the presence of sulphur in the coal; the sulphur is absorbed by the iron and gives to it undesirable properties such as " red shortness." The problem was eventually solved by Dud Dudley, who converted the coal into coke or " char."

Dud Dudley was the son of Edward, Earl of Dudley, who owned iron works in Staffordshire. He left Oxford in 1619 at the age of twenty, and forthwith plunged with considerable energy into the management of his father's iron works. At the outset he was faced with the problem of fuel supply, and he immediately set himself to find a method of using pit coal. After some experimental work he was successful in making coke, which he used in the manufacture of pig iron, and he obtained a patent for his new process from King James I. His patent, he states, was related to " the mistery art of melting iron ore and of making the same into cast iron bars, with coals or pit coals in furnaces with bellowes."* Although Dudley made iron by his process at his own works, it was not taken up by the trade in general; instead, he was faced with violent opposition from vested interests, and all his life he was, in fact, dogged by misfortune. Dudley's rivals were the iron master on the one hand and the charcoal makers on the other. The iron masters were afraid that Dudley would be able to produce cheap iron, and so under-sell them; the charcoal makers were resentful through fear that their monopoly would be destroyed and they would be no longer able to impose their own price, which soared as charcoal became more scarce. Much to the joy of his rivals serious damage was done to Dudley's works by a flood. After he recovered from this blow, complaint was made that his metal was of inferior quality, but the charge was disproved by a test conducted at the Tower of London. Later, by some means of which no account is given, Dudley's

* Campion, " Presidential Address (Scottish Section)" in *Proceedings of the British Foundrymen's Association*, 1913-14, 141.

opponents succeeded in depriving him of his patent rights. He afterwards erected a furnace at Himley, in Staffordshire, but as he made only pig iron and did not possess a forge for the making of pig iron into wrought iron, he could not sell to the consumer, but was compelled to sell to the rival iron masters, who, of course, disparaged the iron and seized every opportunity of handicapping Dudley. Eventually he was imprisoned for debt, after which he was involved in litigation with some partners in an enterprise upon which he had embarked at Bristol; he also suffered losses during the turbulent times of the Civil War. At length he seems to have abandoned his enterprise, and the making of iron by pit coal remained in abeyance for nearly 100 years. "Dud Dudley was not only an iron master but also a founder, for in his *Metallum Martis* he spoke of this country being able to 'supply His Sacred Majesties' other territories with iron and ironware and steel also, by iron and steel made with pit-coals, sea-coals, and peat; and thereby be helpful unto themselves and England and all plantations of His Majesties, on this side and beyond the line.' He also states: 'I also made all sorts of cast-iron ware, as brewing cysterns, pots, morters, and better and cheaper than any yet were made in these nations, with charcoals.'"*

The modern iron industry may be said to commence with the enterprise of the Darbys, and the successful and continued use of coal as a fuel by a member of this family. Abraham Darby, after serving his apprenticeship as a malt-maker at Birmingham, started business at Bristol. He returned from a visit to Holland with some Dutch brass-founders and started a brass works at Baptist Mills, Bristol. Desirous of extending his interests, he attempted to make iron castings in sand, but he and his Dutch workmen were unsuccessful. A Welsh boy named Thomas offered to assist him, and he and Darby worked together one night and made good castings. Thomas continued in Darby's employ, and the process they had evolved was practised in the works owned by the Darby family in secret, behind locked doors, for over 100 years. Darby's partners became alarmed at the probable financial consequences of his continued experimental work, and the partnership was

* *Ibid.*, 146.

dissolved. Darby then took a lease of the Coalbrookdale Works in Shropshire, whither Thomas accompanied him. The Coalbrookdale Works had been in existence for some considerable time previous to Darby's ownership. Darby died in 1717 at the early age of forty, and after an interval of some years the management passed into the hands of his son, who was also named Abraham. Young Darby immediately attacked the fuel problem, and was unsuccessful in his attempts to use the mixture of charcoal and raw coal, but after continuous experimental work for six days and nights in the use of coke, he obtained a very satisfactory metal. The process became standard practice in his works, and Darby's business extended so rapidly that he found it necessary to increase the power of his blowing apparatus by adding "fire engines" to the plant which had been previously driven by a 24-foot water-wheel. Later he built seven new furnaces and installed more fire engines. In 1754 he built a second works at Horsehey, a short distance from Coalbrookdale. Another innovation introduced by this enterprising iron master was the construction of a tram-line with iron rails between his two works at Coalbrookdale and Horsehey. "The success of smelting iron at Coalbrookdale in Shropshire was first imagined to be due to some peculiarity in the coal of that county; but it was gradually discovered that the coals of other districts could be equally adapted to the process, with the result that blast-furnaces became established in one coal-field after another, leading to a continued increase in the quantity of iron produced."* Abraham Darby's introduction of coke fuel marked the beginning of the transition of iron smelting from the woodlands and the forests to the coal-fields, and the application of the "fire engine" to blowing bellows marked the "beginning of the end" of the use of water power for this purpose. The iron industry, which had languished for lack of fuel, now found fuel in plenty, and received a tremendous impetus. In 1740 the number of furnaces in the country was 59, all of them using charcoal fuel; half a century later the number had grown to 106, and in only 25 of these was charcoal used, all the rest using coke. During the management of another Abraham Darby, the son of the

* Galloway, *Annals of Coal Mining*, I. 303.

pioneer of the new fuel, the first bridge of cast iron was built over the Severn at the place now known as Ironbridge. Upon the death of the third Abraham Darby the control of the works passed to his nephew, Edmund, and this member of the wonderful family was responsible for building a rolling mill at Horsehey, and for replacing the old atmospheric engines by the improved steam engines of Boulton and Watt.

Whilst these notable developments were taking place in the manufacture of iron, the conversion of iron into steel was producing the material in which the great mechanical inventors were soon to carry out their ideas. The manufacture of steel and cutlery had gradually become established as an important industry in the Sheffield district. Steel of this period was made by the cementation process, which consists of heating bars of comparatively pure iron in contact with charcoal, so that the iron absorbs carbon and is converted into steel. The carbon is usually diffused irregularly through the metal, so that the metal is frequently of uncertain quality. Not all of the steel which was worked up in this country was manufactured at home; much of it was imported from Germany, and the best steel came from India, where it was made by the "Wootz" method, and was said to be sometimes sold for as much as 5 guineas per pound. Benjamin Huntsman, a Doncaster watchmaker, addressed himself to the problem of discovering a steel of uniformly good quality which could be sold at a reasonable price, his interest having been aroused by his own difficulties in obtaining suitable steel for his clock-making. Night after night he worked at his investigations, first at Doncaster, and afterwards at Handsworth, near Sheffield, but as he maintained strict secrecy, little is known of his apparatus or methods; he is said, however, to have buried in the ground many tons of steel which did not fulfil his requirements in order that no inquisitive person should have the slightest inkling of even his failures. At length, in 1740, Huntsman succeeded in producing a steel by the crucible process, which not only answered his requirements for watch and clock springs, but was superior to the English and Continental steels for making tools and cutlery. He opened a steel works and commenced to make steel by his process, still maintaining close

secrecy. The Sheffield cutlers complained that the steel was too hard and dense to work, and stupidly refused to have anything to do with it, so that Huntsman was driven to seek other customers, and soon established a reputation and a trade on the Continent, until even the sword-makers of Toledo began to use the new steel. Huntsman did not patent his process, and so the Sheffield cutlers, chagrined at their initial refusal to use the material, the value of which they now recognized, made strenuous and, at length, successful efforts to discover the secret of Huntsman's process. It is related that one winter night an old beggar appeared at the door of the works and begged to be allowed to sit near the fire in order that he might warm himself; the man was allowed to enter, and as he soon fell asleep, the work continued apparently unobserved. The "beggar" was a neighbouring iron founder, who, whilst feigning sleep, observed all the details of the process. Other works in Sheffield began immediately to make steel by this method, and so the manufacture of crucible steel by the Huntsman method became general, and is practised with little alteration at the present day. Huntsman's method was really very simple; instead of heating and hammering the bars of cementation or blister steel, as had been done in the past, he broke the bars into small pieces which were melted in crucibles, thus obtaining uniformity of composition. The metal was then cast into the form of chunks or ingots, which were then treated as the billets of blister steel had been treated. The ability to make steel of reliable quality at a reasonable price gave a great impetus to the Sheffield steel-making and cutlery trades.

The use of coke in iron smelting necessitated higher blast pressures in the furnaces than the use of charcoal demanded, a necessity which was accentuated by the tendency to employ larger and more rapidly working furnaces. We have seen that at Coalbrookdale the bellows were driven by atmospheric engines in place of a water-wheel. At the Carron Iron Works in Scotland, which commenced operations in 1759, the problem was attacked in a different manner; the water-wheel was retained, but the bellows were replaced by reciprocating blowing apparatus. The introduction of this apparatus was due to James Smeaton,

who was a friend of Dr. Roebuck, the founder of the Carron Works. Much of the improved machinery used at the works was designed by Smeaton, who seems to have translated into practical form many of the enterprising ideas of the ingenious Roebuck. In the early days of the Carron Works much attention was given to the manufacture of ordnance, and the name of the once well-known gun "Carronade" is derived from these works. Much of the work Smeaton did for the owners of these works was in connection with guns, and machinery and appliances for the manufacture of guns. The Carron Company also did considerable business in the manufacture of domestic vessels, and even to-day a considerable proportion of the product of the foundry section of this famous works consists of what are known in the trade as "light castings"—namely, castings for domestic use and for the building trades.

Apart from cast iron, the only form of iron in use for engineering purposes right up to the time of Bessemer was wrought iron; steel, such as that made by the Huntsman process, being used almost exclusively for implements and tools. Wrought iron was made by refining a small quantity of pig iron on a charcoal hearth, and the refined material was then hammered down into a bar of the required section. The refining method was extremely laborious, and wasteful of fuel, metal, and labour, and the method of producing the bar was obviously crude and incorrect in the extreme. Attempts had been made both in this country and in France to introduce some method of rolling the metal into bar shapes instead of hammering; but these had not been sufficiently successful to warrant more than a very restricted application of them until Cort introduced grooved rolls in 1783. Henry Cort, born at Lancaster in 1740, moved to London in 1765, where, in Surrey Street, Strand, he conducted his business of "navy agent," and dealt largely in iron suitable for ship-building. During the course of his trading he became impressed with England's dependence upon Sweden and Russia for the supply of best iron, and turned his inventive faculties to the problem of home iron manufacture. His invention of 1783, together with the use of other mechanical appliances, considerably increased the output of wrought iron, and this contributed to the increasing use of

machinery. In 1784, the year following the introduction of grooved rolls, Cort effected a revolution in the method of refining the wrought iron preparatory to rolling. In place of the charcoal fire with its small output Cort introduced the method now known as "puddling." In this process the refining of the pig iron takes place in a reverberatory furnace, the metal is heated not by actual contact with the fuel, but by the flame which is caused to "reverberate" from the roof of the furnace down on to the metal. This method of keeping fuel and metal in separate parts of the furnace made it possible to use coal in this process instead of charcoal, thus making this plentiful fuel available for another process in place of charcoal, the supplies of which had, of course, become extremely scarce. Cort unfortunately derived little pecuniary benefit from his inventions. At his own works he lost a considerable sum of money through the malpractices of his partner, to whose creditors his patent rights were handed over; and Cort lived in poverty for a number of years, although for some little time before his death he did enjoy a pension of £200 per annum. It is said that had one iron master alone fulfilled his obligations with regard to the payment of royalties, Cort would have received £25,000 before his death.

Marked improvements in iron and steel manufacture, and the increasing use of machinery, signalized the commencement of a wonderful period of invention in the latter half of the nineteenth century. The development of industrial activity at this period affords a striking example of the interdependence of industry, an interdependence which is a truism in these modern days, but which was not nearly so obvious in the period immediately preceding the industrial revolution. The use of coke in iron smelting encouraged the development of the country's coal reserves, and the working of the coal mines necessitated the employment of engines and pumps. The use of coal as fuel and the use of machinery was applied in other industries, and thus the demand was increased for the products of the iron works. Although the adoption of iron grew rapidly, the metal did not immediately become generally employed in the construction of machinery. The scarcity of iron before the time of the Darbys had necessitated the extensive employ-

ment of timber in the construction of machinery, and for a long time after, not only timber but brass and lead were used to a considerable extent. "Even in the early steam engines and their associated pumping apparatus, almost no iron at all was used. The cylinder and piston, as well as the working barrel and buckets and valves of the pumps, were made of brass; the top of the boiler was made of lead; the great beam of the engines, which constituted the pump handle, was of wood (as its name implies), as were also the pump rods and pump trees, or pipes in the pit; the latter being of the form known as spigot and faucet, bored out of the solid wood and usually only about eight or ten inches diameter. Thus iron was only employed in the lower part of the boiler on which the fire acted (though in some of the earliest engines even this was made of copper); in the chain connections of the beam and other small fittings, and sometimes in hooping the pump trees to impart greater strength to them."* A colliery pumping engine at Whitehaven had a brass cylinder, a copper boiler with a lead top, wooden pumps, and a brass working barrel. But now that iron was becoming cheap and abundant there was not the need for the employment of these other materials. The colliery pump trees were replaced by iron pipes; brass cylinders gave place to cylinders of iron; and cast-iron rails took the place of wood rails on the colliery tramroads. These changes did not, however, take place without opposition. Dr. Desaguliers, in 1744, strongly condemned the use of iron cylinders. "Some people," he said, "make use of cast-iron cylinders for their fire engines, but I would advise nobody to have them; because, though there are workmen that can bore them very smooth, yet not one of them can be cast less than 1 inch thick, and therefore, they can neither be heated nor cooled so soon as the others; which will make a stroke or two a minute difference, whereby a $\frac{1}{8}$th or $\frac{1}{10}$th less water will be raised. A brass cylinder of the largest size has been cast under $\frac{1}{8}$ of an inch in thickness, and at long run, the advantages of heating and cooling quick will recompense the difference in the first expense, especially when we consider the intrinsic value of the brass."†

* Galloway, *op. cit.*, I. 256.
† Desaguliers, *Experimental Philosophy*, II. 536.

The superiority of iron as a material suitable for engineering work gradually became recognized, and this result was hastened by its increasing cheapness. Much engineering progress was also made possible by the advancement in the manufacture of iron and in the production of iron castings, and in this connection the works at Coalbrookdale, and at a later date the Carron Works, played a conspicuous part. Many of the atmospheric engines erected at collieries were of considerable size, and the production of the cylinder castings for these engines was an achievement of no mean order. The cylinder of an engine which was erected at the colliery at Walker-on-Tyne was 10½ feet in length, measured 74 inches in the bore, and was 6½ tons in weight. The boilers for this engine were of wrought iron, except for the tops, which in the case of three of the boilers were made of lead, and in the case of the fourth was made of copper. Some time after its erection the engine was inspected by M. Jars, who remarked in his *Voyages Metallurgiques* that since the construction of this engine it had become customary to construct the boilers entirely of wrought iron, thus superseding the use of two different metals for the purpose. He also stated that the pumps were of cast iron, and that all the pumps he had seen in his journeyings in this country were made of that material. The fact that he considered the remarks necessary seems to indicate that in his own country the use of wooden pumps still continued.

Much of the success achieved by Boulton and Watt in their early steam engines was due to the energy of John Wilkinson, the iron master of Broseley, who made some of their first cylinders, and devised an accurate method of boring steam engines. Wilkinson was a most enterprising man of strong and decisive character, and in building up his huge iron manufacturing business he did much to advance the iron trade in general, and contributed to the increase in the use of machinery in iron works. It was for the purpose of blowing the bellows at his iron works that Wilkinson ordered from Boulton and Watt the first steam engine that was made at Soho. "Wilkinson was a strong believer in cast iron and iron castings. He built the first iron boat which was the forerunner of all subsequent iron and steel vessels. He also erected in Bilston a

cast iron chapel which contained a cast iron pulpit. When he died in 1814, he was, by his own instructions, buried in a cast iron coffin, and a cast iron monument was erected over his grave. Wilkinson was proud of his calling, and had a passion for cast iron even in death."* But just as iron displaced wood and the non-ferrous metals, so wrought iron gradually displaced cast iron for purposes where strength and malleability were required, although the higher cost of wrought iron naturally precluded its use except where some special advantage was to be gained. We have noted that the wooden rails that were used on the early tramways were replaced by cast-iron rails, and at a later period the cast-iron rails were superseded by the rails of wrought iron. The Liverpool and Manchester Railway was the first line to be completely laid with wrought-iron rails. The beginning of the railway era marked the commencement of a further period of heavy demand for iron. In fact, it may be said that almost every new mechanical invention created a new outlet for the products of the iron works, and with equal truth it may be said that every mechanical invention was very largely made possible by the improved quality and output of the same products. The boiler of one of the very early locomotives—the first one constructed by Mr. Blackett—was made of cast iron, and it is not surprising to learn that at the first trial "she blew all to pieces." Locomotive boilers were afterwards made entirely of wrought iron, and continued to be made of that material until the introduction of mild steel, many years afterwards.

The mechanical properties of iron had some influence upon engineering design. The arch form is adopted in the construction of a stone bridge to give stability to the structure, and many of the early cast-iron bridges were constructed to the same design. It was later found, however, that the material lent itself to the construction of bridges of a totally different design, and bridge-building of simple cast iron beams was introduced. Wrought-iron tie rods were frequently employed to give greater strength to the structure. At a later period bridges were constructed throughout of wrought iron; the greater tenacity of this material making it possible for much

* Campion, *op. cit.*, 147.

larger spans to be adopted. About 1830 Fairbairn's experiments on ships directed the attention of ship designers to the possibility of employing iron in ship-building. The vessel which Fairbairn himself constructed went to sea in 1831, and was such a pronounced success that he commenced ship-building on a large scale, and within the next few years he constructed a very large number of vessels at the works which he opened at Millwall in 1835. Thus was wood again displaced by iron, a change which marked the beginning of the building of vessels of much larger capacity than it was possible to construct of timber. Again, the larger engines which were now being made for both land and marine purposes necessitated the manufacture of larger forgings than could be conveniently made by hand hammering. The demand for a heavier blow had been met by the introduction of the helve or forge hammer, which was usually driven by a water-wheel and sometimes by horses. Watt had invented a powerful tilt hammer which he worked first by a water-wheel, and afterwards by a steam engine, and one of these hammers was made by him for John Wilkinson for use at his Broseley forge. These power hammers really resembled a large hand hammer in their design and method of operation. In 1837 James Nasmyth was consulted about the method of making a large forging for a steamship that was then being constructed, and in order to cope with the problem he designed the well-known Nasmyth hammer. The design of the ship was afterwards altered, and rendered the hammer unnecessary. Some time afterwards Nasmyth visited the Creusot Works in France, and upon asking how a certain large forging had been made, was surprised to be told that it was made with his hammer. He learnt upon enquiry that the design which he had discarded had been shown by his partner to some of the Creusot engineers, who turned it to practical use. Nasmyth immediately patented his invention in this country, and constructed a hammer for use at his own works. The manifold advantages of the Nasmyth hammer over the old tilt hammer were immediately obvious, and the steam hammer came into common use and made possible the production of the heavy forgings that were required in the larger engines that were built at that period. These examples serve

to point out some of the sources from which sprang the demand for iron in the early part of the nineteenth century—a demand which was met by the iron manufacturers, partly by the adoption of improved methods and mechanical appliances, and partly by a more extensive use of the iron and coal deposits, and by the opening up of new deposits.

Although iron smelting had been carried on in Scotland for many years, it was not until Blackband ironstone began to be used extensively that the real foundations of the modern Scottish iron industry were laid. Blackband ore is usually obtained in association with a considerable amount of coaly matter—it is, in fact, coal which has become saturated with ferrous carbonate. In 1801 David Mushet, a metallurgist, whose investigations contributed much towards the progress of iron manufacture, pointed out the usefulness of the material as a source of iron supply. Before this time the utility of the ore had been entirely overlooked, and Mushet encountered a considerable amount of prejudice and opposition in his attempts to induce iron masters to use what they contemptuously described as "wild coal" for iron smelting. The use of black-band ore did not become general until the smelting of the iron was facilitated by the use of hot blast, an innovation which was not made until some years afterwards, and which was due to the ingenuity and observation of James Beamont Neilson, at that time manager of the Glasgow Gas Works. Neilson was originally a colliery engine-wright; he became superintendent of the Glasgow Gas Works in 1819, at a salary of £90 per annum, and a few years later, as a result of hard work together with exceptional ability, rose to a position of considerable responsibility. The accepted practice at this time was to blow the air into the furnace as cold as possible. As the result of his attention being called to the inefficient working of a furnace which was situated some distance from its blowing engine, Neilson investigated the question of the combustion of gas in hot air, and observed that combustion took place with increased intensity. Neilson, like many other pioneers, encountered much prejudice, and experienced difficulty in securing a trial of hot blast in actual practice. At length, however, he was allowed to make a trial at the Clyde Iron Works. The first

tests were conducted with the air at a temperature of 80° F., and although encouraging results were obtained even at this low temperature, some years elapsed before Neilson's friends would permit him to make the necessary alterations to the furnaces in order that he might experiment with the air at a higher temperature. At length his plan was put into operation at the Clyde Iron Works, and was immediately acknowledged to be a success. Neilson was very modest about his invention, and refers to it as suitable for application to smiths' fires and foundry cupolas. Its success was so marked, however, that seven years after taking out the patent the process was in operation in practically every iron works in Scotland; and soon afterwards the method became practically universal. Many improvements in plant and methods have been made since Neilson's time, but the principle is still carried out in almost every iron works in the world, the blast being preheated before being blown into the furnace. Attempts were made to infringe the patent which was taken out by Neilson and his partners in 1828, but they obtained heavy damages in a series of law-suits, and were therefore allowed to enjoy the fruits of their enterprise. In 1829, the year after Neilson's patent, only 29,000 tons of pig iron were made in Scotland; sixteen years later the output had risen to 475,000 tons. Huge fortunes were made by iron masters, and by land owners whose land contained deposits of ore, and the whole of this phenomenally rapid growth was due almost entirely to the discovery of blackband ore, coupled with the introduction of hot blast. About the same time the carbonaceous ore of Staffordshire began to be used. This is another type of ore which had been previously looked upon as useless, and which in some instances had been thought fit for nothing better than road metal. Messrs. Bolckow, Vaughan and Co. began to make use of the considerable ore deposits of North Yorkshire in 1836, and some years afterwards a very extensive working of these deposits commenced. The exploitation of the huge beds of ore, together with the growth of railways in this district, are responsible for making Cleveland one of the foremost iron-making districts in the world.

By the middle of the nineteenth century iron had become

extensively used in all directions. Merchandise and passengers were carried about the country on iron railways over iron bridges, and were sent overseas in iron ships; the metal was used alike for the munitions of war and for the machinery of peace; in fact, its uses were unbounded. New furnaces of larger capacity and operated on more efficient lines were constructed in order to cope with the increased demand. Steel, however, was still only sparingly used for constructional purposes. It was not until the invention of the Bessemer process of making mild steel in 1856 that marked advance took place in the steel industry. This invention was perhaps second only in importance to the invention of the steam engine, so far-reaching were its consequences.

Henry Bessemer was a notable example of inherited genius. His father, Anthony Bessemer, was born in London, and at an early age removed with his parents to Holland. At the age of twenty-one we find him in Paris, and at twenty-five he was elected a member of the French Academy of Sciences. Later he was employed at the Paris Mint, and at the time of the French Revolution of 1789 he was imprisoned as a result of a groundless charge made against him. He escaped, however, came to England, and commenced business as a type founder at Charleton, in Hertfordshire. It was here that his youngest son, Henry, was born in 1813, and it was through coming into contact with the work of the type foundry that Henry Bessemer was enabled to develop much of his natural mechanical and inventive ability. When Henry was seventeen the family removed to London, and here young Bessemer made his first successful commercial venture by turning to account his hobby of making art castings. At the age of twenty he exhibited at the Royal Academy. He became interested in the reproduction of artistic work by mechanical means, and was engaged in the production of decorative stamping work. He then invented a method of perforating Government stamps, thus preventing the transfer of old stamps to new deeds. The invention was very successfully adopted by the Government, but Bessemer did not patent it, and, contrary to his expectation and to the promises which were made, he received no reward; and it was not until years after-

wards, when he had acquired fame and wealth as a result of his steel inventions, that he was knighted for his method of perforating stamps. This experience turned the young inventor into a man of business, and the uncompromising attitude he adopted in after-life on several occasions when his steel patents were threatened with infringement is undoubtedly due to the treatment to which he was subjected in his youth. Next followed the invention of a bronze powder, which he proceeded to manufacture by a secret process with the assistance of his brother-in-law. This undertaking was carried on for nearly forty years; it proved to be extremely profitable, and the profits of the early years provided much of the money with which he conducted his long and costly experiments in the manufacture of steel. In addition, whilst still under the age of fifty, Bessemer was responsible for a number of ingenious devices for use in connection with paints, oils, sugar, and other manufacturing processes, and was referred to in the contemporary press on occasion as "the ingenious Mr. Bessemer." At the 1851 Exhibition he exhibited a pump for land and sewer draining, a method for separating molasses from crystal sugar, and a machine for grinding and polishing plate glass. Bessemer then turned his attention to projectiles, and in 1854 he invented a rotating elongated projectile which was proved by tests, which the inventor conducted, to be superior to existing projectiles. The British War Office and the Woolwich authorities declined to consider the adoption of the new invention; in fact, they refused even to participate in the tests. Bessemer was compelled, therefore, to look for encouragement abroad, and succeeded in interesting the Emperor Napoleon III. Napoleon treated the inventor in a very different manner, and not only invited Bessemer to conduct experiments at Vincennes, but placed many facilities at his disposal and advanced money to him to help to cover the expense. The trials proved the superiority of the new projectile to the satisfaction of the French artillery experts, one of whom, Commandant Minnie, said to Bessemer: "The shots rotate properly, but if you cannot get a stronger metal for your guns such heavy projectiles will be of little use." Bessemer was not the man to ignore a suggestion like this, and at once turned his attention to the

provision of a stronger metal than cast iron for the making of guns, and embarked upon the long series of experiments which culminated in the invention of Bessemer steel, a metal whose field of application became much wider than the inventor foresaw when he commenced the investigation.

Bessemer had little knowledge of metal, but believed that people unconnected with a trade frequently brought a fresh and unbiassed mind to bear upon problems connected with it, and were frequently more successful inventors; probably the cases of Huntsman and Neilson were in his mind. With characteristic energy he set himself to become acquainted with the existing state of iron manufacture in the country; he read all the available literature on the subject, and visited works in all parts of the country. Having absorbed as much knowledge as possible regarding existing practice, he settled down again in London and established an experimental works in an old factory at St. Pancras. Bessemer had no intention of producing steel, but merely wished to obtain an improved quality of iron. He commenced first by trying to improve pig iron by adding pieces of blister steel to it. Melting was conducted in a reverberatory furnace to maintain the purity of the metal; a free supply of air was introduced to permit of the more complete combustion of the fuel. The accidental occurrence of almost completely removing the carbon from the metal by a too copious supply of air suggested to Bessemer the possibility of obtaining low carbon metal by blowing air into the molten pig iron, and so removing the carbon instead of mixing cast iron and steel together. The experiment was conducted in the furnace in order to keep the metal hot, and at the end of the operation it was found that the pig iron was converted into soft malleable iron. Knowing that the temperature increased during the blowing in of the air, Bessemer built a suitable vessel into which he poured liquid cast iron and proceeded to decarbonize it by the same method, but without the application of external heat. At the end of twenty minutes the metal was tapped out, and it was found that this experiment was also successful in producing an ingot of malleable iron. The work had occupied eighteen months of the inventor's time, but the result of this experiment appeared to indicate that

success had at last been achieved; subsequent events, however, showed that this apparent success was largely due to the chance using of suitable material, and much more investigation had to be carried out before the Bessemer process was put on a commercial basis.

Some years previously Nasmyth had attempted to refine iron by blowing steam into it, and Kelly, an American, had worked on lines similar to Bessemer, but the process had not been pursued very far. Bessemer may have known of the work of these investigators, but it was he himself who proved decisively through his experiments at Baxter House, St. Pancras, that it was possible to remove some of the constituents of cast iron by blowing air through the liquid metal, and converting it into malleable iron, and at the same time obtain a temperature higher than had previously been attained. Bessemer demonstrated the process to his friend Rennie, who persuaded him to write a description of it, and present the paper at the forthcoming meeting of the British Association at Cheltenham, and so at the 1856 meeting of the Association Bessemer was announced to read a paper on "The Manufacture of Malleable Iron and Steel without Fuel." The paper created a tremendous sensation, and James Nasmyth spoke to the originality of the method, thus disproving the charge made afterwards in some quarters that Bessemer had copied Nasmyth's deoxidizing process. Fourteen days later the first licence was taken out by the proprietors of the Dowlais Iron Works, and within one month £27,000 had been realized by the sale of licences. Surely never had an inventor such a success; but the success was short-lived, and was quickly followed by what appeared to be overwhelming disaster. The early licensees followed Bessemer's instructions, but did not get his results. From all over the country came reports, not of the expected success, but of utter failure. The very magnitude of the hopes that had been raised a short time ago only intensified the gloom and disappointment which greeted the first failure, and the chorus of praise which had been showered upon the inventor gave place to an almost unanimous chorus of denunciation. One paper referred to the invention as "a brilliant meteor that had flitted across the metallurgical horizon for a short space, only to die out in a

train of sparks, and then to vanish into total darkness."* Referring to the attempts which were made to obtain steel by his method, Bessemer observes: "I was present at some of these trials, and saw the utter failure that resulted with the quality of metal operated upon. It is a curious and scarcely creditable fact that not one of the iron masters who had previously felt such abundant confidence in the success of the process as to back their faith with large sums of money, took any trouble whatever, or offered any practical or scientific help towards getting over this unlooked-for difficulty. They all stood by, mere passive and inert observers of the fact, not one of them lifting up a finger or stretching out a hand to save the wreck."† So completely was the world convinced of the futility of the whole idea, that the British Association declined to print the paper in its *Transactions*.

The only man who was not crushed by the sense of failure was the one most intimately affected, the undaunted inventor himself. He began to investigate the matter, and enlisted the aid of several eminent chemists and metallurgists to make analyses. The analyses revealed the fact that the defects were due to the presence of phosphorus, and that Bessemer's process did not remove the phosphorus. He had been successful in his own experiments because, quite by accident, he had been using Blaenavon pig, a brand of iron very low in that element. Not knowing that the phosphorus contained in the pig iron had anything to do with the matter, the licensees had used ordinary pig, comparatively high in phosphorus, with the results which have been described. The investigations showed that the remedy lay in one of two directions—either to use pig iron comparatively free from phosphorus, or to attempt to remove the phosphorus from ordinary pig iron. Unfortunately Bessemer attempted to solve the latter problem, and made costly and laborious experiments which only ended in failure. After eighteen months of useless work, he gave up the attempt to rid iron of phosphorus and turned his attention to the possibilities of using iron manufactured from low phosphorus ores. Bessemer now obtained a supply of pure Swedish iron, and losing no time in testing it, found that he was once again able

* Quoted by Bessemer, *Autobiography*, 170. † *Ibid.*, 170.

to repeat his initial success, and make good malleable iron by simply blowing air through the molten metal. He had now put his process upon a sound basis, the causes of the failures were thoroughly understood, and were provided for. It only remained for him to arrange for an abundant supply of low phosphorus iron, and to induce steel manufacturers to resume the working of his process which they had abandoned. The manufacturers, however, remembered only too well the high hopes which had been so rudely shattered two years before, and refused to entertain any thought of the process, so that Bessemer and his friends were themselves compelled to commence the manufacture of steel by the new process in a works built for that purpose in Sheffield.

It should be explained that by the new process steel could be made by simply stopping the blowing at a suitable time so as to leave a sufficient amount of carbon in the metal; if the blowing were carried further, however, so as to remove more carbon, a metal similar in composition to the wrought iron made by the puddling process was produced; the metal made by the Bessemer process was stronger, however, because being obtained in the fluid state it was not weakened by the inclusions of slag that occur in wrought iron made by the puddling process. It will be seen that the metal had some of the properties of both steel and iron, and it became known, therefore, as "mild steel."

The Bessemer Company still encountered difficulty at their own works. At one time failure again seemed to confront them owing to the oxidation not only of the constituents of the metal which were to be removed, but also of the metal itself, which consequently became rotten. The trouble was overcome by adopting the suggestion of Robert Mushet, the son of David Mushet, of adding manganese in the form of "speigel" in order to remove the oxygen from the metal and restore it to its original properties. The process of melting was also improved upon after experience had been gained. At first the practice was to grade the steel according to carbon content, and then remelt it, thus following Huntsman's method; Gorannson, a Swedish iron master, who had commenced to make Bessemer steel, assisted the company in altering their

process in order to make the steel direct in one operation. Further improvements were made in the heat-resisting materials used for lining the converters, and the manufacture on a large scale of suitable low phosphorus pig iron from the pure hæmatite ores of North Lancashire and Cumberland was commenced by several companies formed for the purpose; and the final success of the Bessemer process was then established beyond all possible dispute. It was soon impossible for the world to ignore the wonderful new metal in spite of the prejudice created by its first failure. The next step was to make known the qualities of the new metal and to induce consumers to use it. At first this was found to be very difficult, but the company's own products were themselves their best advertisements, and a number of engineers soon realized the advantages to be gained by using a metal so much stronger and more ductile than wrought iron, and so much cheaper than the existing types of steel. The first use to which Bessemer steel was put was the making of tools. Its value as a material of engineering construction, and particularly for the making of rails in place of wrought iron, was quickly realized, however, by a few far-sighted men. In 1861 Crewe Station was laid with Bessemer steel rails, an innovation which was soon seen to be justified by the longevity of the material. A rail laid at Camden in the following year lasted as long as seven double-sided iron rails before it was turned over, and in another test one face of a steel rail outlasted eleven rails of iron. The first steel boiler was constructed by Mr. Daniel Adamson, of Hyde, in 1860, and a few years later that engineer was using the material extensively for this purpose. Steel tube plates were used in locomotive boilers on the Lancashire and Yorkshire Railway in 1867, and in the following year the first steel locomotive boiler was made at the London and North-Western Railway works at Crewe; this boiler continued to be used for sixteen years. At the International Exhibition of 1862 Bessemer exhibited a number of sample steel forgings, consisting of cylinders, shafts, gun-barrels, etc., and all but the most sceptical were now convinced of the value of the process. No sooner had the advantages of the invention been demonstrated than a demand for the issue of licences began; the

applications were granted, but not at the price at which they had originally been offered. Having placed the risk of the pioneering work on the shoulders of Bessemer, the steel-makers were made to face the competition of the vigorous new rival or to pay the increased royalty demanded by the inventor. Most of them chose the latter alternative, and it is said that Bessemer received over a million pounds in royalties from his steel patents alone. The manufacture of Bessemer steel quickly spread to other countries. In 1864 the United States patent was bought by an American syndicate; the process had already been introduced into Sweden, and it rapidly spread to other Continental countries. It is noteworthy that in several foreign countries the process was appropriated without licences, or without royalties being paid, owing to some legal quibble which had been devised. Regarding the Bessemer Company, "the first year of working resulted in a loss of £729, and in 1859, the second year, the loss was £1,100. In 1860, simultaneously with the appearance of the converter in its present form, there was a profit of £900, and seven years later the profit had risen to £28,000."*

Ever on the lookout for fresh applications of his metal, Bessemer made strenuous efforts to induce ship-builders to use steel plates in place of wrought-iron plates, pointing out to them the advantages of greater ductility, and of using a thinner and lighter plate to give the same strength as the weaker wrought iron. One ship-builder ordered enough steel plates to make a barge, and was so satisfied with the results that he at once commenced to build a larger vessel. The ship-building world was much impressed by the advantages of the *Cuxhaven*, a ship of 1,251 tons, which on her maiden voyage would probably have been destroyed by a cyclone which swept over her in the harbour of Calcutta but for the strength of the steel plates, which resisted the full force of the elements, and even after collision with another vessel the steel ship did not take a drop of water. The *Engineer*† remarked at the time: "She is now in dock at Liverpool bearing her honourable scars as so many awards of merit and testimony to the accuracy of all that can

* Lange, *Bessemer, Govannson and Mushet*, 17.
† October 20, 1865.

be said in favour of Bessemer plates." Bessemer was less successful in inducing the naval authorities to use steel armour plates, and it was not until some years afterwards that such plates were made of steel. It is curious to note that, although Bessemer set out to invent a new metal for making guns, when the metal was invented Woolwich Arsenal declined to use it for this purpose, and decided to continue to make guns of cast iron.

The manufacture of Bessemer steel to-day appears in this country to be giving place very largely to open hearth steel, although it is less likely to be superseded in the United States and on the Continent. Notwithstanding, it is impossible to overlook the far-reaching consequences of Bessemer's invention. The effect upon civilization of the development of railways and steamships is obvious, and it is no exaggeration to say that the almost universal application of these cheap forms of transport is due to the provision of a cheap and durable metal made by this process, a process which at the time of its introduction was entirely different in plan, method of procedure, and results from any previously known mode of manufacture. The Bessemer process, in point of the importance of its effect upon industrial development, has been classed with the invention of the steam engine and the introduction of the penny postage, and a speaker before the Iron and Steel Institute in 1890 declared that no one great event "has been more potent in preparing the way for the higher civilization that awaits the coming century than the pneumatic process for the manufacture of steel." In his *Autobiography* Bessemer observes: "Some idea may be formed of the importance of the manufacture, and of how much the people of Sheffield lost by their prejudice and incredulity, when I state the simple fact that on the expiration of the fourteen years' term of partnership of our Sheffield firm, the works, which had been greatly increased from time to time entirely out of revenue, were sold by private contract for exactly twenty-four times the amount of the whole subscribed capital of the firm, notwithstanding that we had divided in profits during the partnership a sum equal to fifty-seven times the gross capital. So that, by the mere commercial working of the process, apart from the patent,

each of the five partners retired from the Sheffield works after fourteen years, having made eighty-one times the amount of his subscribed capital, or an average of nearly cent. per cent. every two months—a result probably unprecedented in the annals of commerce."* The inventor devoted his declining years to scientific hobbies, and carried out costly but unsuccessful experiments upon a steamship designed with a view to preventing sea-sickness. He was knighted for his early invention of a method of preventing fraud upon the revenue authorities, and received innumerable other honours. He died at Denmark Hall in 1898, at the age of eighty-five.

The success of the Bessemer process and, when its utility was recognized, the growing demand for mild steel stimulated invention and brought many other processes into being; none of them, however, were of any great importance except the open hearth process, which, ever since its introduction, has been a formidable rival of the Bessemer process. In the open hearth process use is made of the regenerative furnace of Sir William Siemens, and the open hearth will always be associated with the name of this inventor.

Siemens was born at Lenthe in Hanover, in 1823, and was a member of a family whose scientific achievements were considerable. At the age of twenty he paid a visit to England for the purpose of introducing to Messrs. Elkington, of Birmingham, a method of electrically depositing silver so that a smooth surface was obtained instead of the rough surface that had previously been produced. In the following year he returned to England, and continued to reside in this country until his death, which occurred as the result of a street accident in 1883. Siemens and his brother Frederick were distinguished investigators in many branches of science, and contributed largely to scientific literature, but probably none of the inventions of Siemens were of more importance in their consequences than the regenerative gas furnace and the open hearth process of making mild steel. The two brothers had given much thought to the work of Joule in connection with the determination of the mechanical equivalent of heat, and also to the question of the conservation of energy, and as a result they

* Bessemer, *op. cit.*, 177.

attempted to construct a regenerative steam engine. Although a number of engines were constructed the idea was eventually abandoned on account of the rapid deterioration of the heating apparatus. Still anxious to effect conservation of heat, Frederick Siemens suggested to his brother in 1857 the possibility of effecting such economy in high temperature furnaces. Experiments in this direction met with more practical success, and a number of furnaces designed to make use of waste heat were built and successfully used for various purposes; it was not, however, until gas fuel was adopted that success was achieved with the larger sizes. In 1851 the first improved furnace was installed at a glass works in Birmingham, and was so successful that its use rapidly extended not only in the glass-making industry, but for zinc distillation and for metallurgical purposes such as reheating iron and steel, heating crucibles of blister steel in the crucible steel-making process, and also for puddling.

The Siemens furnace consists of a bath-shaped hearth upon which the material to be heated is placed. The gas fuel is made in separate gas producers, and is heated by passing through brick regenerators before entering the furnace, and the air which passes into the furnace to assist in the combustion of the gas is similarly heated. As the gas and air enter the furnace at a high initial temperature, less fuel is required to raise the furnace to the working temperature, and as the brick regenerators are heated by the hot waste gases as they pass from the furnace, much fuel is consequently saved. Faraday was greatly impressed by the simplicity of the Siemens furnace, and lectured upon it in the last popular lecture he delivered at the Royal Institution. Siemens' first attempts to make steel in his furnaces were not very successful. Several furnaces were constructed in various parts of the country and in France, but were afterwards abandoned. Eventually he opened an experimental steel works of his own at Birmingham, and soon demonstrated the success of his process by producing quantities of steel. In some instances his raw material consisted of light iron rails which were being superseded by Bessemer rails, and the iron rails were converted into steel by the Siemens process and rerolled into rails. In the meantime the brothers Martin

erected a furnace at Sireuil in France from Siemens' plans, and succeeded in making steel from scrap iron together with pig iron. Siemens himself, however, modified his process in that he caused the iron to be purified by oxidizing the impurities with iron ore. At length the possibility of making steel in the open hearth furnace from pig iron, with or without the additional iron ore, became established, and the process began to be commercially adopted. The first successful plant for the manufacture of mild steel by the Siemens process was laid down by the London and North-Western Railway at Crewe in 1868, and the adoption of the process spread rapidly in this country and on the Continent. The name Siemens-Martin, which was subsequently given to the open hearth process, is an acknowledgment of the part played by P. and E. Martin in the pioneering days. Later in life Siemens devoted much attention to attempts to make steel in his furnace direct from the ore without first converting it into pig iron. Large works were erected for the purpose, and were abandoned as the attempts proved to be fruitless. Despite his failures Siemens' faith in the possibility of achieving the "direct" process remained unabated until his death.

The growing popularity of Siemens mild steel among engineers is due to the fact that the manufacturing process can be more carefully controlled, as the process of conversion is much slower than is the Bessemer method and permits the withdrawal from the furnace of samples of steel which may be analysed and tested while the process of manufacture is proceeding. Progress in the Bessemer method cannot be gauged so accurately, and is judged largely by observation, founded upon previous experience. For this reason Siemens steel is generally assumed to be of a more uniform composition, and it can be more easily made within specified limits. It is used extensively for plates and sections for constructional work, and for castings and forgings. The use of Bessemer steel is now largely confined to the making of steel rails and other heavy rolled sections.

The enormous demand for steel which sprang up after the invention of the Bessemer and Siemens processes again directed attention to the problem of the utilization of phosphoric ores,

large quantities of which are found in North Yorkshire, Staffordshire, and in other districts. A satisfactory solution was suggested by Sydney Gilchrist Thomas and his cousin, Percy C. Gilchrist, who showed that by introducing a suitable lining of basic material into the converter a good quality steel could be obtained from phosphoric iron. The Gilchrist Thomas invention was known as the basic process, and its success in connection with the manufacture of Bessemer steel led to the use of basic linings in the Siemens furnace and the production of Siemens basic steel. The manufacture of basic steel by both processes has grown rapidly, and has resulted in the utilization of large quantities of British ore previously useless for steelmaking, with a consequent check on the importation of foreign ore, which was beginning to come into this country in large quantities, in order to obtain a copious supply of ore suitable for use in the Bessemer process. It is noteworthy that the phosphorus from the iron, together with the limestone, passes into the slag or scum which is poured off the metal, and on account of the phosphorus contained in it basic slag is much in demand for use as a fertilizer, and constitutes a very valuable and profitable by-product of the basic steel works. Some prejudice with regard to the use of basic steel for purposes where great reliability is required still exists, and for engineering work of the highest class acid is still frequently specified. On the Continent and in the United States basic steel is used for engineering work of all descriptions.

It was largely due to Sir Joseph Whitworth that steel superseded iron as the metal used in the manufacture of guns. Whitworth quickly saw the potentialities of Bessemer's new metal for the making of ordnance, but believed that greater ductility was necessary. In order to obtain ductility without the porosity due to the blow-holes usually found in ductile steel, he invented the process with which his name is usually identified, and subjected the liquid steel to enormous hydraulic pressure. Not only guns but engineers' forgings of other kinds were made from Whitworth's fluid compressed steel. The boiler shafts of H.M.S. *Invincible*, built in 1876, were of Whitworth's improved metal, and weighed 63 tons, whereas if they had been made in wrought iron the weight would have been

97 tons; and in the case of forgings for other ship-building and constructional purposes similar economies in the weight of metal, together with increased strength, were obtained by using high-class steel in place of wrought iron. Whitworth afterwards turned his attention to the manufacture of armour plate of improved quality, and succeeded in producing plates which at that time were considered invulnerable, but which were also lighter in weight than the armour plate previously used.

The making of high carbon steel as distinct from the mild steel of the Bessemer and open hearth process is carried out to-day in principle on very much the same lines as in the days of Huntsman. The manufacture of alloy steels possessing special properties for particular purposes is of more recent growth, and has led to considerable changes in the application of steel to engineering construction, and to even more remarkable changes in the performance of tools for cutting metal, resulting in rapid and uniform production in engineering workshops. As is well known, the ordinary carbon steel tool is hardened by heating to a red heat, and suddenly cooling in water or some other medium; it is then "tempered" by raising it to a given temperature much lower than the ordinary red-heat, and depending upon the carbon content of the metal and the purpose for which it is to be used. If in the tempering it is raised to too high a temperature, the hardness is lost, and the tool reverts to its original comparatively soft state, and is useless for cutting metal until it is again hardened. These properties on the part of the cutting tool limit the speed at which metals may be cut in engineering workshops by ordinary carbon steels, as the friction between the tool and the metal heats the end of the tool and consequently releases, as it were, hardness, in the same way that the hardness would be released by any other kind of overheating. In 1868 Robert Mushet, whose suggestions had benefited Bessemer so greatly, introduced the type of self-hardening steel which bears his name. This is a steel containing about 2 per cent. of carbon, the same proportion of manganese, and from 5 to 8 per cent. of the comparatively rare metal, tungsten. The peculiar property of this steel is that it can be heated to a much higher temperature

than the ordinary carbon steel without losing its hardness, thereby allowing metal to be cut at a much higher speed than previously. Mushet or tungsten steel found a useful place in workshop practice for a number of years, and is still used to a large extent, although its place is gradually being taken by the modern high-speed steels.

High-speed steels first came into prominence at the Paris Exhibition in 1900 when the famous American firm, the Bethlehem Steel Company, exhibited the material at work on mild steel castings, which were being cut at the hitherto unheard-of speed of 150 feet per minute. So great was the cutting speed that the edge of the tool became red-hot, and the colour of the turning from the material operated upon showed that a high temperature had been attained. The high-speed steel contained chromium in addition to the other constituents of tungsten steel. Its remarkable properties were due, however, not only to the composition, but to the method of heat treatment to which the tools were subjected after forging, a method which was discovered as the result of investigation by two members of the Bethlehem Company, Taylor and White. Since this steel was first brought to the notice of engineers other brands of high-speed steel have been put on the market by steel-makers in America, in this country, and on the Continent. Most of these steels are carbon steels containing quantities of two or more elements, the combination of which, together with the "heat treatment," gives to the tool the property of retaining its hardness even at high temperatures. The heat-treating process is important, and usually consists of raising the tool to a white heat and allowing it to cool in air or in oil. It is not necessary to quench suddenly, as is the case with the ordinary carbon steels. The use of the high-speed cutting tools is working a revolution in the engineering machine shop practice. Not only can metal be cut more rapidly, but larger cuts can also be taken than was formerly the case, so that production is increased considerably. Furthermore, the increasing use of forgings and castings of hard tough alloy steel has largely been made possible by the availability of a suitable cutting metal for machining such forgings. The use of such cutting tools has led to the design

of lathes, milling machines, and other machine tools of more robust construction in order that they may withstand increased stresses and the greater risk of vibration. In addition to their use for cutting purposes alloy steels have come into extensive use for engineering purposes where special properties are necessary. Manganese steel is largely used for purposes where hardness is required, such as in grinding and cutting machines for mines and quarrying work. Nickel steel, on account of its tenacity and toughness, is used in the manufacture of armour plating, and turbine shafts which rotate at a very high speed. The addition of chromium to nickel steel produces a metal which is even superior in its properties to nickel steel, and is now largely used for motor-car axles. A recent use of chrome steel is in the manufacture of stainless cutlery.

The requirements of the engineer for steel of the highest quality have contributed to the growing use of electric furnaces, and it is probable that in the future electric steel will be more widely used. At the present stage of development, however, the economic usefulness of the electric furnace is limited. Owing to the high temperatures obtained, refining of comparatively impure metal can be carried to a point unobtainable by other processes, and high quality steel of great purity may therefore be made. The chief drawback is the high cost of the process, due mainly to the large amount of electric current consumed. It is on account of the cost that electric steel is not likely to rival mild steel for ordinary constructional and general purposes, as the latter steel is of a sufficiently good quality, and is produced at a reasonable price. A more attractive result is obtained in the making of the highest class of metal for axles, tyres, guns, etc. The metal now commonly used is produced from specially selected high-priced pig iron. The newer method which will probably come into wider use is to convert the commoner type of pig iron into mild steel by one of the older processes, and to refine the molten steel in an electric furnace. The cost in this case compares favourably with the older method on account of the lower-priced raw material used. An even wider field of usefulness will probably be found for the electric furnace in the production of small castings of the highest class and in the making of tool steels.

The processes involved in making these varieties of steel have been confined up to the present to the crucible method originated by Huntsman nearly two centuries ago. Here the electric furnace holds its own, even with regard to cost, because although the electrical method is costly, the crucible method is even more costly. During the European War the electric furnace was used for remelting the large quantities of steel turnings produced in the manufacture of shells; furnaces of this type are also coming into use for the various alloys which are employed in making high-speed and other alloy steels.

The production of iron and steel having special properties, coupled with the general improvement in quality—the response to the engineer's demand for stronger and lighter metal—has only been made possible by continual research, by careful scientific control which is exercised at every stage of the manufacturing process, and by rigid systems of testing and inspection of the finished product. The importance of accurately determining and controlling chemical composition was brought home to Bessemer in the days of his early failure, and for many years every iron and steel works has had its chemical laboratory. Even so, until recently the amount of empiricism has been very great, but the rule of thumb has now been considerably reduced and the experience of the practical worker is supplemented by the scientific assistance of the metallurgist. Much progress has been made since the discovery of accurate methods of measuring high temperatures, and in no branch of industry has the introduction of pyrometers been of such assistance as in the manufacture and heat treatment of high-speed steels. In well-equipped works temperatures are no longer judged, as was formerly the case, entirely by the experienced eye of the worker, but every heating process is controlled by the use of pyrometers. The microscopic examination of metals has also become of prime importance. It is recognized that it is not sufficient to know the constituents of a metal, but that it is also necessary to understand its internal structure. The study of the micro-structure of steel was originated by Dr. Sorby, of Sheffield, many years ago, but it is only within the last quarter of a century that the science of metallography has received the attention it deserves. In

recent years use has been made of X rays to detect hidden defects. Many different constituents of iron and steel have been discovered, and the state of the structure supplies valuable information relating to the effects of the heat treatment which the metal has undergone. The microscope and the pyrometer are invaluable not only in research work, but for the investigation of failures and in the control of operations. The work of the designer has been aided by improved methods of mechanical testing of materials. Accurate information relating to the mechanical properties of a metal have done much to assist the engineer to reduce the weight of modern machines and to replace the old-fashioned engines of unwieldy design by the well-proportioned machines of to-day.

It will be seen that progress in engineering during the last hundred and fifty years has been intimately bound up with progress in the iron and steel industry. The development of every new invention has been made possible by the production of suitable metals, and every stage in the progress of iron and steel manufacture has called mechanical invention to its aid; the steam engine, the steam hammer, the hydraulic press, have all made their contributions. The laborious manual operations involved in handling heavy materials have been superseded by elaborate mechanical and electrical appliances which in turn have made possible the manufacture of forgings of ever-increasing weight for use in the engineering and shipbuilding works of the present century. A modern power station, a locomotive, or a steam-ship is an epitome of the work of the iron and steel maker in producing materials of the highest class with varied properties, and the modern iron and steel works itself provides many examples of much that is best in modern engineering invention. Electrical engineering has called forth its particular type of iron and steel, and in turn has contributed to the equipment of modern works, the majority of which are now driven by electric motors, and in many cases derive their power from their own well-equipped power-houses.

CHAPTER IX

GAS AND OIL ENGINEERING

VERY little was known of the properties of natural and artificial gas prior to the beginning of the nineteenth century. There appears in the *Philosophical Transactions* for 1667 a quaint communication written by Thomas Shirley at a time when the knowledge of natural gas was practically negligible, and entitled, "The Description of a Well and Earth in Lancashire taking Fire by a Candle Approached to it."*

"About the late end of February 1659, returning from a Journey to my House in Wigan, I was entertained with the relation of an odd Spring situated in one Mr. Hawkley's Ground (if I mistake not) about a Mile from the Town, in that Road which leads to Warrington and Chester. The People of this Town did confidently affirm that the Water of this Spring did burn like oyle; into which error they suffered themselves to fall for want of a due examination of the following particulars. For when we came to the said Spring (being five or six in Company together) and applied a lighted Candle to the Surface of the Water; 'tis true, there was suddenly a large Flame produced which burnt vigorously; at the sight of which they all began to laugh at me for denying, what they had positively asserted; But I, who did not think myself confuted by a laughter provided upon inadvertency, began to examine what I saw; and observing that this Spring had its eruption at the Foot of a Tree, growing on the Top of a neighbouring Bank, the Water of which Spring filled a Ditch that was there, and covered the Burning-place, I applied the lighted Candle to divers Parts of the Water contained in the said Ditch, and found, as I expected, that upon the Touch of the Candle and the Water the Flame was extinct. Again, having taken up a Dish full of water at the flaming Place, and held the lighted

* Quoted by Hunt, *A History of the Introduction of Gas Lighting*, 2.

Candle to it, it went out, Yet I observed that the Water, at the Burning-place, did boil, and heave, like water in a Pot upon Fire, tho' by putting my Hand into it, I could not perceive it so much as warm. This Boyling I conceived to proceed from the Eruption of some bituminous or sulphureous Fumes; considering this Place was not above 30 or 40 Yards distant from the Mouth of a Coal-Pit there: And indeed Wigan, Ashton, and the whole Country, for many Miles compass is underlaid with Coal. Then, applying my Hand to the Surface of the Burning-Place of the Water, I found a strong Breath, as it were a Wind, to bear against my Hand. When the Water was drained away, I applied the Candle to the Surface of the dry Earth, at the same Point where the Water burned before; the Fumes fook fire, and burned very bright and vigorous. The Cone of the Flame ascended a Foot and a half from the Superficies of the Earth; and the Basis of it was of the Compass of a Man's Hat about the Brims. I then caused a Bucket full of Water to be pour'd on the Fire, by which it was presently quenched. I did not perceive the Flame to be discoloured like that of sulphurous Bodies, nor to have any manifest scent with it. The Fumes, when they broke out of the Earth, and press'd against my Hand, were not, to my best Remembrance, at all hot."*

Of greater value than the investigation of Shirley was that undertaken by Dr. Clayton, who was for some time Rector of Crofton at Wakefield in Yorkshire, and who was prompted to action also by the emission of gas in the Wigan district. Clayton went a step further than Shirley, and actually distilled coal in a retort, this being the first record of distillation of coal and collection of resultant gas. The report of this experiment is contained in a communication which he made to Boyle. While it was not published until some years later, it is evident that it must have been written during the latter half of the

* Nearly two hundred years later, in 1846, a similar effect was observed on the River Wear, near [illegible] Bridge, when gas exuding from the bed of the river [illegible] on the surface, and when lit gave an appearance of the river apparently on fire. It is also recorded that in 1851, during the course of boring operations on Chat Moss, lying between Liverpool and Manchester, natural gas was burned at the end of a 12-inch diameter pipe, and produced a flame 8 to 10 feet long.

seventeenth century, as Boyle died in 1691. A copy of the record appeared in the *Philosophical Transactions* of the Royal Society, 1739-1740, but bearing no date. The original copy is now in the British Museum,* and is accompanied by a letter from Boyle's son written in 1740 vouching for the description "as far as concerns the sincerity and faithfulness of my copying it from the original, which I found among my father's papers and in his own hand-writing." The paper was entitled: "An experiment concerning the Spirit of Coals, *Inter Alia*, in a Letter to the Hon. Mr. Boyle by the late Rev. John Clayton, D.D., communicated by the Right Rev. Father in God Robert Lord Bishop of Cork to the Right Hon. Earle of Egmont, F.R.S."; and runs as follows: "Having seen a Ditch within two miles from Wigan in Lancashire wherein the water would seemingly burn like Brandy, the Flame of which was so fierce, that several strangers have boiled eggs over it, the People thereabouts indeed affirm that about 30 years ago it would have boiled a piece of Beef; and that whereas much Rain formerly made it burn much fiercer, now after Rain it would scarcely burn at all. It was after a long-continued season of Rain that I came to see the Place, and make some Experiments, and found accordingly that a lighted Paper, though it were waved all over the Ditch, the Water would not take Fire. I then hired a person to make a Dam in the Ditch and fling out the Water, in order to try whether the steam which arose from the Ditch would take Fire, but found it would not. I still, however, pursued my Experiments, and made him dig deeper; and when he had dug about the Depth of half a yard, we found a Shelley Coal, and the Candle being then put down into the Hole, the Air catched Fire, and continued burning. I observed that there had formerly been Coal pits in the same Close of Ground; and I then got some coal, from one of the pits nearest thereunto, which I distilled in a Retort in an open Fire. At first there came over only Phlegm, afterwards a black Oil, and then likewise a Spirit arose, which I could no ways condense, but it forced my Lute, or broke my Glasses. Once when it had forced my Lute, coming close thereto, in order to try to repair it, I observed that the Spirit which issued

* Additional MSS. 4437. Quoted by Hunt, *op. cit.*

out caught fire at the Flame of the Candle, and continued burning with violence as it issued out in a stream, which I blew out, and lighted again, alternately, for several times. I then had a mind to try if I could save any of this Spirit, in order to which I took a turbinated Receiver, and putting a Candle to the Pipe of the Receiver whilst the Spirit arose, I observed that it catched Flame, and continued burning at the End of the Pipe, though you could not discern what fed the flame; I then blew it out, and lighted it again several times, after which I fixed a Bladder, squeezed and void of Air, to the Pipe of the Receiver. The Oil and Phlegm descended into the Receiver, but the Spirit ascending, blew up the Bladder. I then filled a good many Bladders therewith, and might have filled an inconceivable number more; for the Spirit continued to rise for several Hours, and filled the Bladders almost as fast as a man could have blown them with his mouth, and yet the Quantity of Coal I distilled was inconsiderable. I kept this Spirit in the Bladders a considerable time, and endeavoured several days to condense it, but in vain. And when I had a mind to divert strangers or Friends, I have frequently taken one of these Bladders, and pricking a hole therein with a pin, and compressing gently the Bladder near the Flame of a Candle till it once took fire, it would then continue flaming until all the Spirit was compressed out of the Bladder; which was the more surprising because no one could discern any Difference between these Bladders and those which are filled with common Air. But then I found, that this Spirit must be kept in good thick Bladders, as in those of an Ox, or the like; for if I filled Calves Bladders therewith, it would lose its inflammability in 14 Hours, though the Bladder became not relax at all."

Although numerous other experimenters, stimulated by the results obtained by Shirley and Clayton, carried out researches into the products of coal, William Murdock was the first to turn to practical account the light-giving properties of coal gas. We have already described the important part taken by Murdock as "right-hand man" to Boulton and Watt in the construction and development of their steam engines.* While at Redruth

* *Supra*, 139.

in Cornwall in charge of the Boulton and Watt engines, the subject of the extraction of gas from coal occupied his attention to no small degree. It is evident from Murdock's own writings that he first turned his thoughts to the subject of gas lighting in 1791, for in his paper before the Royal Society* he wrote: "It is now nearly 16 years since in the course of experiments I was making at Redruth in Cornwall upon the quantities and qualities of the gas produced by distillation from different mineral and vegetable substances, that I was induced by some observations I had previously made upon the burning of coal, to try the combustible property of the gases produced from it as well as from the peat, wood, and other inflammable substances; and being struck with the great quantities of gas which they afforded, as well as the brilliancy of the light, and the facility of its production, I instituted several experiments with a view of ascertaining the cost at which it might be obtained, compared with that of equal quantities of light yielded by oils and tallow. My apparatus consisted of an iron retort, with tinned iron and copper tubes, through which the gas was conducted to a considerable distance; and there, as well as at intermediate points, was burnt through apertures of various forms and dimensions. The experiments were made upon coal of different qualities, which I procured from different parts of the kingdom for the purpose of ascertaining which would give the most economical results. The gas was also washed with water, and other means were employed to purify it."

There is little doubt that about 1792 Murdock's house, still standing in Cross Street, Redruth, was first illuminated by coal gas. Scanty record exists of the preliminary experiments which led to this practical demonstration of the illuminating properties of gas, but an interesting reference is made to these early researches in a letter written in 1876: "Some time since when in the West of Cornwall, I was anxious to find whether any one remembered Murdock. I discovered one of the most respectable and intelligent men in Camborne, Mr. William Symons, who not only distinctly remembered Murdock, but

* Murdock, "An Account of the Application of the Gas from the Coal to Economical Purposes," in *Transactions of the Royal Society*, 1808. Murdock was awarded the Rumford Medal for this paper.

had actually been present on one of the first occasions when gas was used. Murdock, he says, was fond of children, and not unfrequently took them into his workshop to show them what he was doing. Hence it happened that on one occasion this gentleman, then a boy of seven or eight, was standing astride Murdock's door with some other boys trying to catch sight of some special mystery inside—for Dr. Boaze, the chief doctor of the place, and Murdock, had been busy all the afternoon. Murdock came out, and asked my informant to run down to a shop near by for a thimble. On returning with the thimble the boy pretended to have lost it, and, whilst searching in every pocket, he managed to slip inside the door of the workshop and then produced the thimble. He found Dr. Boaze and Murdock with a kettle filled with coal. The gas issuing from it had been burnt in a large metal case, such as was used for blasting purposes. Now, however, they had applied a much smaller tube, and at the end of it fastened the thimble, through the small perforations made in which they burned a continuous jet for some time."* Murdock's researches in gas making continued for many years, and in 1798 he constructed apparatus for making, purifying, and storing gas on a large scale; this source of supply he used for illuminating many of the buildings at the works at Soho. In 1802, in celebration of the Peace of Amiens, Murdock gave a public display of gas lighting at the Soho works. William Matthews† says of this display that "he had the inexpressible gratification of witnessing, in 1802, Mr. Murdock's extraordinary and splendid exhibition of Gas-Lights at Soho. This remarkable illumination was the first public display of the kind in this country, and at the time produced a very strong impression upon the inhabitants of that populous town" (Birmingham). He adds: "The illumination of Soho Works on this occasion was of extraordinary splendour. The whole front of that extensive range of buildings was ornamented with a great variety of devices that admirably displayed many of the varied forms of which gas light was susceptible. This luminous

* First quoted by Smiles, *Men of Invention and Industry*, 136-137. The writer was Mr. M. S. Pearce.

† Matthews, *Historical Sketch of the Origin, Progress, and Present State of Gas Lighting* (1827).

spectacle was as novel as it was astonishing; and Birmingham poured forth its numerous population to gaze at and to admire this wonderful display of the combined effects of science and art." The advertisement arising from the display of gas lighting at Soho resulted in many North Country works applying for gas installations, and Murdock was engaged before long in equipping installations in various works, notably the cotton factory of Phillips and Lee, of Salford, Burley and Kennedy, of Manchester, and Gott and Sons, of Leeds. When Watt visited Glasgow in 1805 he found that gas was in general use, and wrote in the following terms to Boulton: "The new lights are much in vogue here; many have attempted them, and some have succeeded tolerably in lighting their shops with them. I also hear that a cotton mill in this neighbourhood is lighted with gas. A long account of the new lights was published in the newspapers some time ago, in which they had the candour to ascribe the invention to Mr. Murdock. From what I have heard respecting these attempts, I think there is full room for the Soho improvements, though, when once they see one properly executed, it will have numerous imitations."

The next pioneer of gas lighting was F. A. Winsor, of Frankfort, who appears to have been interested in the problem as the result of researches conducted in France and Germany. He possessed a fertile imagination, but his novel schemes were more idealistic than practical. Experiencing difficulty in finding financial support in his inventions and ideas, Winsor in 1804 came to London to enlist the aid of British financiers. He displayed great energy and resource in giving publicity to his schemes, and delivered a series of lectures on "Gas-Light" in the Lyceum Theatre. These lectures, which were well supported by influential audiences, were accompanied by practical demonstrations of the production and illuminating properties of gas. In the same year he published two pamphlets, the titles of which, on account of their interest to-day, are given in full. The first, "The Superiority of the New Patent Coke, over the use of coals, in all family concerns, displayed every evening, at the Large Theatre, Lyceum, Strand"; the second, "Account of the most ingenious and important national discovery for some Ages. British Imperial Patent Light

Ovens and Stoves by which alone 1000 % are saved and gained in Light, Heat, and some valuable products for British Manufacturers, Commerce and Navigation; as proved by an exact account. Current of Profit and Loss affixed: respectfully dedicated to both Houses of Parliament and all Patriotic Societies; and recommended to all the learned in Physics and Chemistry; but particularly to all gentlemen interested in the English Fire Insurance Offices; for a considerable reduction of the most dreadful accidents in human life, and for the promotion of so many national advantages, by F. A. Winsor, the second inventor and improver." In discussing the lighting and heating properties of gas in the course of these pamphlets, Winsor remarks: "In repairing of old houses, and building of new ones, such arrangements may be made as to have every apartment lighted and heated from the kitchen, or from the wash-house, whichever proves most convenient." Equally optimistic is he as to the heating value of coal gas, for "one tasty crystal globe on a marble pedestal, or otherwise will also light, and sufficiently heat, the largest room during winter. . . . We may light and warm our streets, playhouses, lighthouses, and all public buildings, in a far superior style, and much less expensive manner, than we can do with wax, tallow, or oils." In 1809 he made an application to Parliament for authority to organize a joint-stock company for the purpose of lighting the streets of London by gas. The company was to be called "The National Light and Heat Company," but the application was successfully opposed by William Murdock. To indicate how little was known of gas lighting at that period, the following passage in the evidence of Murdock before the Parliamentary Committee is worthy of notice. "Do you mean to tell us," asked one member, "that it will be possible to have a light without a wick?" "Yes, I do indeed," answered Murdock. "Ah, my friend," said the legislator, "you are trying to prove too much." It is scarcely surprising that strange notions were entertained in those early days respecting the properties of gas, since the product was something entirely different from anything that had been experienced up to that time, and wholly revolutionary in comparison with the liquid and solid illuminants with which earlier generations had been familiar. "Sir

Humphrey Davy ridiculed the idea of lighting towns with gas, and asked one of the projectors if it were intended to take the dome of St. Paul's for a gasometer. Sir Walter Scott also made many clever jokes about the absurdity of lighting London with smoke, although he shortly afterwards adopted the said 'smoke' for lighting up his own house at Abbotsford. It was popularly supposed that the gas was carried along pipes on fire, and that hence the pipes must be intensely hot. Thus, when the House of Commons was first lighted with gas, the architect insisted on the pipes being placed several inches from the wall for fear of fire, and Members might be seen applying their gloved hands to them to ascertain their temperature, expressing the greatest surprise on their being found as cool as the adjoining walls."* Despite the first rebuff which Winsor and his subscribers received, they eventually succeeded, in 1812, in obtaining the charter of incorporation, whereby the first statutory Gas Company was formed, known as "The Chartered Gas Light and Coke Company."

About this period other pioneers entered the field, chief among whom were Samuel Clegg from the Soho works, Northern of Leeds, Pemberton of Birmingham, and two chemists, Henry of Manchester and Accum of London. Clegg was undoubtedly the ablest of these early workers, and his engineering training, combined with a sound chemical knowledge, enabled him to surpass his rivals who were not so suitably qualified. The presence of Clegg in the field confronted Boulton and Watt with a serious competitor. When Murdock was in Manchester awaiting the delivery of apparatus for installation at Phillips and Lee's Cotton Works at Salford, he wrote to Messrs. Boulton and Watt at the Soho Works on December 23, 1805, as follows: "Gibson has finished his job at Macclesfield (which answers very well), and he is this day arrived at Manchester, where he must remain idle till I receive an answer from you, as none of Mr. Lee's lighting apparatus has yet arrived. . . . Please to let me know if the second receiver is sent off by land or by water; if materials cannot be forwarded in a more expeditious way than they have hitherto been done, it is of no use to think of taking orders here, for your old servant Clegg is manu-

* Smiles, *Boulton and Watt*, 404.

facturing them in a more speedy manner than it appears can be done at Soho." In 1813 Clegg was appointed engineer to Winsor's Chartered Company, in the hope that under his guidance the Company might be saved from the disaster which was rapidly overtaking it. During his four years of management Clegg did excellent work, and succeeded in placing the business on a sound footing. He retired from the company in 1817, and henceforward devoted himself to the construction of gas-works in various parts of the country, his most important works being at Halifax, Manchester, Coventry, and Hyde. He introduced many improvements in gas manufacture, notably in the purification of crude gas and in the prevention of the back flow of gas by the invention of the hydraulic main.

It is of interest to note in passing that the famous "Continental System" of Napoleon in the opening years of the nineteenth century stimulated the progress of gas manufacture. In 1808 Benjamin Cook, in the course of a description of apparatus designed for the manufacture of gas on a small scale, calls attention to the economies and advantages of gas lighting, "especially now through the present rupture with Russia and the other northern Powers, the want of importation of tallow has increased to a very considerable height the price of candles, soap, etc. The rise in price of candles has, of course, been the occasion for an equal rise in oil, as lamps are substituted in the place of candles."* From this point onwards the progress of gas lighting was rapid. Numerous Metropolitan Gas Lighting Companies were launched during the first half of the century, and they operated with varying degrees of success. Keen and often reckless competition prevented the majority from being very successful. This wasteful competition, as was abundantly proved, militated as much against the interest of the consumers as of the companies. The continual breaking up of the streets and the difficulty of localizing the frequent heavy leakages that occurred in the mains and service pipes was another evil consequent upon and aggravated by the competitive system. The whole width of a busy street would often be seen torn open to lay bare the half-dozen large main gas pipes by which it was traversed.

* Nicholson's *Journal*, XXI.

It was often a matter of difficulty for workmen to determine which particular main was the one belonging to the company by which they were employed. The result was that service pipes were frequently attached to mains other than to those of the company who were collecting the rental. An ingenious device was adopted for discovering connections of this kind; holes having been drilled in the respective mains, a ferrule with a flexible tube was inserted, the other end of the tube being drawn on the nozzle of a portable bellows. When this latter was actuated, a pulsation of the contained gas was set up; and this, extending to the lights in the neighbouring tenements, revealed the source of supply.* This harmful competition was eliminated when, during the years 1854 to 1858, the scheme of districting was adopted, whereby each company was required to operate in a well-defined area. Reduced prices and increased business were the immediate results of this change, and there can be little doubt that the general public benefited to as great an extent as the companies. Previous to the year 1825, companies or local authorities had established gas works in most of the large provincial towns, and during the next ten years the majority of medium-sized towns followed their example. By the middle of the century even the smaller villages had installed their own gas-supply.

Among provincial towns Liverpool was one of the first to follow the example of the Metropolis and install gas lighting. Early in 1816 preparations were made for introducing into Liverpool gas "which had been used with such brilliant effect in some parts of London."† Experimental lights were displayed in front of the Town Hall, which are thus described by an eye-witness: "Liverpool Gas-lights.—Two large gas-lamps with three burners in each, have been lighted up with gas, and exhibited for the last few nights, in front of the Town Hall. The light is so brilliant that a person may with ease discover the hour with his watch at the distance of twenty or thirty yards. We understand that it is intended to light the dock-lamps by this method; and we trust it soon will become general."‡ Shortly after this it was announced that a Liver-

* Newbigging, *A Treatise on Coal Gas*, I. 57.
† Baines, *History of Liverpool*, 569.
‡ *Liverpool Mercury*, January 26, 1816. Quoted by Baines, *op. cit.*, 569.

pool Gas Light Company had been formed, and had so far arranged its plans that it would be able to give the whole town the benefit of brilliant light in a short time. "To show the superiority they possessed over the convex lamps it is only necessary to observe the gas lamp at the coachmaker's, in Dale Street, lately put forth, which gives nearly as much light as all the other lamps in the street."*

Some time elapsed before gas was used for power purposes. Certain crude experimental gas engines had been constructed at the end of the nineteenth century, but in design they followed closely the steam and hot air engines of that period, and were far from being practicable from a commercial point of view. Numerous publications and patents show, however, that prior to 1860 nearly all the modern types of gas engines had then been discovered and tried in an experimental form. The most valuable source of information respecting the development of the gas engine, up to the period of its extensive commercial use, lies in the Patent Records of the British, French, and American Offices. With these early experimental engines are associated the names of Robert Street, Samuel Brown, W. L. Wright, James Johnson, and William Barnett.† It is recorded‡ that a Brown engine was fitted in a boat that ran experimentally on the Thames, and another one fitted to a road carriage. However, the first internal combustion engine to attain any real commercial success was the Lenoir engine, patented in France in 1860. While its underlying principles had been anticipated by previous inventors, it succeeded in regular operation where the earlier designs had failed, and there is reason to believe that the success of the Lenoir engine was due in no small measure to the good preparations which characterized its design. By 1865 there were between three and four hundred such engines at work in France, and a hundred engines were made by the Reading Ironworks Company in this country.§

In 1861 Nicholas A. Otto, of Germany, hit upon a new idea in gas engine design and developed it to the point of inventing

* *Ibid.*, March 22, 1816. Quoted by Baines, *op. cit.*, 569.

† For an account of these early engines, see Carpenter and Diederichs, *Internal Combustion Engines*.

‡ *Mechanics' Magazine*, December 24, 1825.

§ *Practical Mechanics' Journal*, August, 1865.

the well-known four-stroke gas engine. This four-stroke or four-cycle engine carried out its operations in the following manner: The first or suction stroke drew in the gases; the second or compression stroke compressed the mixture, at the end of which stroke the explosion took place, and the work was done during the third, or power, stroke; while the fourth and final stroke expelled the products of combustion from the cylinder. Otto's patent practically amounted to a monopoly. Hence other manufacturers were forced to turn their attention to the development of the two-cycle engine, as distinct from the Otto four-cycle. About 1885, however, Otto's patent claims fell, and the field was open for manufacturers to proceed with the four-cycle engine. In this country various four-cylinder engines were brought out during the years 1885 and 1898, conspicuous among which were the designs of Crossley, Daimler, Hornsby, and Akroyd. "Wherever a supply of gas is obtainable, as in every town and many villages for the last forty years, the gas-engine performs useful service; but the fuel, prepared specially for the purpose of illumination, is expensive. In small workshops where power is not a principal factor of production, this may not matter, but in factories where the cost of power is a considerable factor and has to be reduced to the lowest possible sum, there are obvious objections."* In these latter cases, either producer or water gas may be used. Producer gas is formed by the incomplete combustion of coke, and water gas by the action of air and steam upon red-hot coke. Waste gases from blast furnaces and coke ovens are also suitable as fuel for gas engines, and their application for this purpose was first suggested in 1892 by Mr. B. H. Thwaite. These discoveries have led not only to the increased use of gas engines but to their construction in larger units. whereby still greater economies are effected. A cheap and reliable form of prime mover is therefore readily available, and can be used to advantage in those places where the high price of coal would prohibit the use of steam plant, but where material containing carbon is at hand, such as wood refuse, sawdust, and other materials from which gas can be made.

A more recent type of internal combustion engine is the oil

* Cressy, *Outline of Industrial History of England*, 137.

engine, which resembles the gas engine in many respects. In the oil engine, as in the gas engine, power is produced by the explosion and consequent expansion of a mixture of inflammable material and air. In the case of the oil engine, however, the "inflammable fluid" used consists of vapour obtained from the oil instead of permanent gas. Light and heavy oils are used; light oils may be defined as those which are readily volatile at ordinary atmospheric temperatures, while heavy oils are those that require special heating or spraying processes in order to produce an inflammable vapour capable of forming the explosive mixture to be supplied to the cylinders. Of light oils the most important and best-known is petrol, which consists of constituents which first distil over in the process of purifying petroleums or paraffins. The principal application of the oil engine is to the propulsion of vehicles, and is due to Gottlieb Daimler, a German engineer, and Benz, a French engineer, who worked independently of each other. Steam-driven road vehicles had been constructed from time to time ever since the early days of the locomotive. Most of them were clumsy contrivances of limited application. In 1884 Daimler built a small engine to use benzine as a fuel, in which the Otto cycle already described was followed. Daimler also devised the carburettor in conjunction with his engine. The engine appears to have been intended for stationary work and for the propulsion of boats, and it was first used for this purpose, but in 1886 the inventor fitted it to a bicycle. The engine was placed between the front and rear wheels and drove the rear wheel by means of a belt. The results were so successful that the inventor further studied the application of his engine to the propulsion of road vehicles, and in 1889 he built a small two-cycle engine. His work attracted attention and inspired a measure of confidence in the possibility of successfully constructing a self-propelled road carriage. The manufacturing rights were acquired by the well-known French engineering firm of Panhard and Levassor, and very soon the company was making and selling motor-cars in France. Benz built his first engine in 1885; using the two-stroke principle, though the four-stroke cycle was soon afterwards employed. Contemporary with these inventions was the work of Count de Dion

and M. Serpollet, who constructed steam road carriages, the steam being rapidly generated in a "flash" boiler, which was part of the equipment of the carriage.

The Paris-Rouen motor run of 1894, in which fourteen petrol and six steam driven cars took part, created much interest. In the run from Paris to Bordeaux and back, which was held later, the total distance of 730 miles had to be completed in one trip. This, together with other conditions, imposed a severe strain upon a form of vehicle still in its infancy, and the successful finish of the trip by nine of the forty-two competing cars established the motor-car as a serious product of engineering, and gave an immense impetus to its manufacture in France. Sir David Solomon, who was one of the first people to import a car into this country, arranged an exhibition run in which several cars took part at Tunbridge Wells in 1895, and thus aroused public interest in this country. There is little doubt that the natural expansion of the motor industry in Great Britain has been retarded by legislation. In the early days of the motor vehicle it was regarded as being little different from the locomotive, and hence legislators felt called upon to protect the public from the dangers of such traffic on the roads. It was not until 1896 that the Act was repealed which limited the speed of motor vehicles travelling on British roads to 4 miles an hour. This Act required that each vehicle should be in charge of three persons, one walking in front carrying a red flag (hence known as the Red Flag Act), and that the speed in towns should not be greater than 2 miles per hour, and 4 miles per hour on the highway. This restrictive legislation was removed by the passing of the Locomotives on Highways Act, which made a distinction between motor-cars and traction engines, and relieved from the tight restriction any vehicle propelled by mechanical power the weight of which (unloaded) did not exceed 3 tons, or together with that of a trailer (unloaded), 4 tons. It further sanctioned the driving of such vehicles at a speed of up to 14 miles per hour, but gave authority to the Local Government Board to reduce the speed if it was considered to be necessary—an authorization of which the Board availed itself by fixing the speed limit at 12 miles per hour. The year 1896 also saw the founding of the English

Daimler Motor Company, and in this year too the Ford Motor exhibition was held at the Crystal Palace. A few years later the motor-car had become a comparatively familiar vehicle on our roads.

The design of the early cars followed as far as possible the design of horse-drawn conveyances, and the body frequently took the form of a dog-cart or a wagonette, the engine being tucked away somewhere under the seat. These early cars were frequently very unreliable; the arrangement of the mechanical parts was inconvenient, and the passengers were exposed to the weather. However, progress was rapid; easy accessibility of the mechanical parts was secured by placing the engine in front of the car and the gear-box under the foot-board. Mechanical design was improved as a result of practical experience on the road, and cars as a consequence became less troublesome. Greater protection against the weather was afforded by the adoption of the tonneau body, and by the provision of hoods, wind-screens, and other protective arrangements. Other improvements that have taken place include better systems of ignition and cylinder cooling, lighter weight engines for given powers, non-skidding tyres, and improved body construction. The evolution of the rapid and reliable motor vehicle necessitated the further revision of legislative restrictions. The Act of 1896 gave great impetus to the industry, but the low speed limit was unnecessarily irksome, and the Act afforded no relief in the case of motor vehicles suitable for trade or public service purposes, because such vehicles if kept within the specified weights would not carry a paying load, and would therefore have been unprofitable. If larger weights were carried so as to make the operation of heavy motor vehicles profitable, then they were subject to the same regulations as traction engines, and there was therefore no advantage in using them. Strong representations on the subject made by well-known associations of motor manufacturers and motor traders on behalf of the commercial interests of the country led to the passing of the Motor-Car Act of 1903, which raised the speed limit to 20 miles per hour, while empowering the Local Government Board to impose a 10 miles per hour limit in dangerous areas, and in order to

prevent abuse introducing the well-known system of registration of cars and the licensing of drivers. The interests of the heavy motor users were put into the hands of the Local Government Board, who were given power to increase the maximum allowable weights. As a result of the exhaustive enquiries made by a Departmental Committee set up for the purpose, the Board issued the Heavy Motor-Car Order of 1904, which permitted the maximum weight of a motor-car to be increased from 3 tons to 5 tons, and for the weight of a motor-car and trailer to be increased from 4 tons to 6½ tons. This order made it possible to run heavy motor vehicles profitably, and it marks the commencement of the modern road transport of passengers and merchandise which has had such a phenomenal growth in recent years, and which is causing rapid and far-reaching changes in the commercial and social life of the country.

When the utility of the self-propelled vehicle had been demonstrated and its operation had been freed from unnecessary legislative restrictions, horse-drawn traffic began to be rapidly displaced, especially in large populous centres. Figures furnished by the London Traffic Branch of the Board of Trade show that in 1911 only 13 per cent. of the passenger vehicles in London were horse-drawn, while two years later the number had decreased to 6 per cent., thus showing that the transition in the method of propulsion of passenger vehicles had been almost completed. The percentage of horse-drawn trade vehicles in 1911, however, was as high as 94, and this had only fallen to 88 in 1913, from which figures it appears that the change to mechanically propelled trade vehicles commenced at a much later period. The annual censuses taken by *Motor Traction* in typical London thoroughfares indicate the rate at which the transition has taken place with regard to certain classes of vehicles. In 1907, during one day's observation, it was noted that 30 per cent. of the 3,236 omnibuses in Fleet Street were self-propelled, five years later only 2,770 buses passed along Fleet Street, and all of them were self-propelled. The decreased number is due to the higher speed and greater passenger capacity of the mechanically propelled bus against those of its picturesque

horse-drawn predecessor, and indicates how road congestion is reduced by the transition. The passing of the horse-drawn cab had only begun in 1908; the census showed only 48 motor cabs against 1,902 horse-drawn cabs. In 1914 the change was almost complete; there were 1,652 motor cabs and 74 of the horse-drawn variety during a given period. The censuses with regard to passenger vehicles of all kinds show that 20 per cent. were self-propelled in 1908, but in 1914 the percentage had increased to 96. *Motor Traction* figures relating to trade vehicles show a similar result to those of the Board of Trade which have just been quoted. In a typical main road leading out of London, 1 per cent. of the trade vehicles was self-propelled in 1906, while in 1913 the percentage had increased to 10.

The social effects resulting from the introduction of the self-propelled road vehicle are gradually increasing in importance. Originally the motor-car was viewed as a possible substitute for the horse-drawn conveyance, but it soon became apparent that the former vehicle by reason of its greater speed, its tirelessness, and consequent wider radius of operation, was capable of being used for a great many purposes outside the scope of the horse carriage. Motor riding and motor touring became popular, and brought into being a new class of road users, and many people who had never dreamed of becoming owners of horse carriages soon became zealous devotees of the new kind of travel, and took up motoring, not for the utilitarian purpose of getting from place to place, but purely as a pastime. The light car and the cheap American have brought the motor within the reach of men of moderate means, while the motor-cycle has enormously widened the circle of adherents to safe road travel. The addition of the side-car to the motor-cycle, though unmechanical in principle, has proved satisfactory in practice, with the result that two people, or even a small family, may share in the joys of motor-cycling. The cheapening of motor travel has broken down the barrier which at one time made motoring the sport of the rich, and to-day thousands of artisans run their motor-cycles and side-cars. Undoubtedly motoring has exercised the beneficial effects that must always result from any increase of travel facilities; places of beauty

and interest are explored, the range of personal contact with other people and other ideas is widened, and pleasure is obtained in a form which at the same time broadens one's experience. The arrival of the motor charabanc has given an impetus to motoring for pleasure. In the years immediately preceding the war, this type of vehicle was used as a novel substitute for the horse wagonette and charabanc. Since the war the motor charabanc has rapidly taken a position which the horsed vehicle could not possibly fill by reason of its limited radius of operation. Briefly, the charabanc brings the advantages of motoring within the reach of the man who does not wish, or cannot afford, to possess a motor vehicle, but who does not object to sharing his pleasures with strangers. Motoring has become democratic, and the factory worker shares the fascination of road travel with the owner of the luxurious car. The charabanc is now a much more comfortable, roomy, and reliable vehicle than was the similar vehicle of pre-war days, and its popularity is indisputable.

Undoubtedly road travel has become more popular through the diminished service and high fares on the railways which obtain as a result of the war. Increased motor manufacturing resources were, moreover, called into existence during the war, and on its termination became available for the manufacture of vehicles for civil purposes. The effect of increased travel upon the countryside itself must not be forgotten. The one-time quiet country road, particularly if it leads away from a large city, is now often crowded with motor vehicles, and roads have to be widened and sharp corners removed in the interests of safety. The peaceful village and the sleepy country town become centres of bustling activity at the week-ends and at holiday times. The old-fashioned hostelry described by Dickens, which had frequently become little more than a village ale-house since the railways had diverted traffic from the roads, comes into its own again with the development of motoring. The former sharp distinction between the outlook of the countryman and that of the town dweller tends to disappear, for villages, however distant from the railway, have been brought within closer distance of the town as the result of the rapid and flexible method of road travel. The establish-

ment of motor omnibus services in districts sparsely served by railway and tramway systems has still further helped to bring the town nearer to the villages and the villages nearer together. To-day the town worker may live in the surrounding country and daily travel to and from his work with ease.

Although the mechanical road transport of goods was not developed until much later than passenger motoring, the social changes it is silently working are scarcely less remarkable. One of the principal advantages of road transport is its mobility. Instead of goods having to be carted from factory to railway and again from railway to customer at the other end, they may now be loaded directly into the motor waggon and taken straight to the customer. The saving in the cost of handling and the reduction of the total time taken to transport the goods is evident, as are also the advantages of road transport to the cotton industry where goods are usually transported from town to town to undergo the various treating and finishing processes. Most important of all is the transport of foodstuffs. Farm and dairy produce are now brought direct from the producer to the market, or to the retailer, in a much fresher condition than when brought by rail. The elimination of intermediate handling and the more rapid delivery are responsible for this, and even where the cost of road transport is greater than that of rail transport, the former is frequently cheaper in the end, as the proportion of waste produce is less. An important feature in many rural districts is the daily collection of milk from the farms in the neighbourhood by a motor lorry which conveys the milk direct to the dairy in the town, and on its return takes back the empty cans from the previous delivery. The tradesman's motor delivery van which extends the radius of his custom is now well known. The rapid road transport of stock from a central headquarters to the branches of a multiple shop company or to a number of independent shopkeepers, and the preparation of food at a central bakery and its conveyance to a number of restaurants in outlying districts, are other significant features of modern commercial life which have been made possible by the motor-car.

The petrol engine is rapidly being introduced into agriculture. The motor tractor which drags the plough or other implement

after it, although not so well known as in Canada and the United States, where conditions are vastly different, is nevertheless making its appearance, and the motor fitted to a plough or other implement, or driving machines in the barn, is also much more frequently seen than was the case a few years ago. Among the special types of self-propelled vehicles are motor fire engines and motor ambulances. Again, the mobility of our army during the recent war was increased enormously by the employment of a gigantic fleet of over 32,000 motor lorries, which carried supplies and ammunition from the railway right up to the firing line. In addition, there were in use during the war some 13,000 motor ambulances and light passenger cars. The utility of that remarkable engine of war, the tank, which was of such importance, is largely due to the existence of the light and powerful petrol motor.

The internal combustion engine is now extensively used for the propulsion of ships and boats. Its growing popularity for this purpose is due to the low weight and smaller bulk of the engine and necessary stock of fuel, as compared with the weight and bulk of the steam engine and boilers and the reserve of coal. The general cleanliness and simplicity of operation have also contributed to the popularity of the oil-engine propelled vessel, particularly in the case of small pleasure craft. Engines burning heavier types of oil, such as the Diesel engine, are employed for larger vessels. Submarines and destroyers are now frequently equipped with internal combustion engines of high power. An important development is the use of oil instead of coal as the fuel of steam-ships. Originally applied to vessels of comparatively small size such as destroyers, where space and weight are important considerations, oil fuel was soon seen to possess further advantages of easy replenishing and great cleanliness, and is to-day burned in vessels of all types and sizes, including many of the largest and most modern Atlantic liners.

One of the most notable applications of the petrol engine in recent years has been in connection with aviation. Many centuries ago men's minds dwelt upon the possibility of travelling through the air, and accounts exist, both legendary and historical, of more or less successful attempts to ascend into

the skies. The inauguration of practical aeronautics, however, took place when the Montgolfier brothers in France designed their first balloon, consisting of a large bag in which the air was heated by a fire underneath the bottom of the bag. The air in the balloon expanded, becoming less dense than the surrounding atmosphere, and the vessel consequently ascended. Balloons were afterwards filled with hydrogen, and in 1821 coal gas was used for this purpose. Considerable interest was aroused by the ascent of Count Zambessari's balloon in London in 1783, but the balloon was unaccompanied by an aeronaut, and it was not until the following year that Tyler established the claim to be considered the first man to ascend into the air in this country. Attention both here and on the Continent was directed to the design of a dirigible balloon which would not be at the mercy of the air currents, and it is related that as early as 1854 Giffard built a dirigible balloon fitted with a small steam engine. In 1884, Renard built a dirigible airship in France, but the first really practical airship was that constructed in 1903 by another Frenchman, Lebaudy. In the meantime, other designers had been busy with flying machines that were heavier than air. It was thought that success would be achieved if the principles of bird flight could be understood and copied; some of the early designs, therefore, were of machines with elaborate "flapper" wings. Other inventors came into the field from time to time with machines of the plane type, thus anticipating the present-day aeroplane, notable among which was Sir George Cayley's aeroplane of the early nineteenth century. The machine constructed by Stringfellow and Hudson in 1848 was on the lines of Cayley's design. Many of these machines were of excellent design from the point of view of keeping aloft, but they suffered from carrying steam or compressed air propelling plant that was too heavy in comparison with the lifting capacity of the machine. Sir Hiram Maxim's experiments were carried out on a large steam-driven aeroplane, which came to grief during trials in 1893.

Much valuable information relating to the principles of flight was obtained as a result of experimental work with artificial wings and gliders; notable among the workers who were so engaged was Lilienthal, a Berlin engineer, who, in

1871, commenced his work with wings attached to his body. Lilienthal's method was to take his glider on to an elevated position and glide down to a lower level in a slanting direction; he kept his balance and controlled the steering by movement of the body. This notable pioneer made over 900 glides, the longest of which was 300 metres in length. He met his death in 1896 when a biplane glider in which he was travelling fell a distance of 80 metres and the scientist was killed. Soon after this time experiments with man-lifting kites were made by Pilcher, who had been associated with Maxim in the construction of his machine. Pilcher also lost his life as the result of a fall. At this period Wilbur and Orville Wright commenced a long and systematic series of experiments with gliders in the United States. They improved upon Lilienthal's design inasmuch as the machine was controlled by a forerunner and a vertical rudder. During three years of work they accumulated a good deal of data concerning the air and relating to wing design, and their later models may be said to have been complete aeroplanes without the means of propulsion. The rise of the motor-car industry was instrumental in providing a light and reliable form of prime mover in the petrol engine, and the Wright brothers fitted a 16 horse-power motor of their own design to a biplane glider and succeeded on December 13, 1903, in flying 260 metres against a wind in fifty-nine seconds. This was the first real flight in an aeroplane. The inventors continued their experiments at Dayton, and succeeded in staying in the air for much longer periods. Later, in 1906, interest in the aeroplane was aroused in Europe, and M. Santos-Dumont, a Brazilian, who had a few years previously accomplished notable work with dirigible airships, succeeded in making several short flights in France. Two years afterwards Wilbur Wright gave sensational flying exhibitions in the same country, whilst his brother was busy in America in connection with aeroplane contracts for the American Army Signal Corps. These successes and the work of other aviators proved the practicability of the aeroplane, and from this time progress was rapid, particularly in France. In 1909 the work of English aviators became known, and successful machines were constructed in this country by Cody, an American who afterwards

became a naturalized Englishman, and by A. V. Roe. Cody had gained much experience with man-lifting kites in connection with the British Army. In July, 1909, the world was startled by the first successful flight across the Channel by a Frenchman, M. Blériot. The first Englishman to fly was J. T. C. Moore-Brabazon, who, however, accomplished his early flights whilst learning the art in France. A fresh impetus was given to aero design and performances by the offer of valuable prizes for the accomplishment of certain flying feats of height or distance, and by the holding of the memorable Flying Meeting at Rheims in 1909. This was followed by a similar meeting at Blackpool in the autumn of the same year, when a sensational flight against a gale by the French aviator Latham indicated the reliability of the new means of transport under adverse conditions, and did much to inspire confidence in its safety. Other flying meetings followed, and aviators rapidly improved their performance, heights were increased, longer distances were flown, and they remained in the air for longer periods. Probably the surest indication of progress was the increase of cross-country flying, which would have been impracticable without skill in the manipulation of the machine, and confidence in its strength and in the reliability of the motor. The Frenchman Paulhan flew from London to Manchester in 1910 and won the *Daily Mail* prize of £10,000. An Englishman, Graham White, gave a fine performance in the same competition by flying from London to Lichfield. Further progress was exceedingly rapid, and as the design and reliability of aeroplanes and engines improved, and as the skill and daring of the pilots increased, so did the performance of aircraft become more astonishing. In 1911 there was a competition for another *Daily Mail* prize of £10,000 for a successful flight round Great Britain. This prize was also won by a Frenchman, Lieutenant Conneau, who flew under the name of Beaumont. The competition was flown in mixed weather and under conditions that taxed to the utmost the resources of man and machine. Among the few competitors who finished the course was the British aviator, the redoubtable Cody.

Government interest was shown by the appointment of a Departmental Committee as a consultative body with Lord

Rayleigh as Chairman, and after further consideration the Government decided to arrange British military trials as a means of deciding upon the types of aeroplanes likely to be useful for military purposes. The competition was open to the world, and took place on Salisbury Plain in August, 1912. Although this country had entered the field of aviation later than the Americans and the Frenchmen, the fact that twenty out of the twenty-three machines entered were of British construction is significant of the rapid development that had taken place. The tests were of a most searching and exhausting character, which in themselves indicated great confidence in the performance of the machines. Each competing aeroplane had to make a three hours' qualifying flight with a passenger, during which an altitude of 4,500 feet had to be attained and a height of at least 1,500 feet had to be maintained for one hour of the test. Tests were also made to ascertain the climbing and alighting powers of each aeroplane, and the rapidity with which it could be dismantled, reassembled, and flown again. The prize of £4,000 open to the world was awarded to Cody, who also received a further prize of £1,000 open to British subjects.

The aeroplane requires to be driven by a prime mover that is at once light, powerful, and absolutely reliable, and must constantly be working under conditions which would be considered abnormally trying if they were imposed on engines used for any other purpose. The development of the petrol engine in connection with motor-car work provided the very engine required, and its application to aeroplanes made possible the utilization of the inventions and discoveries of those many able workers who had been engaged in trying to solve the problem of flight. Aero engine design had necessarily proceeded along somewhat different lines from those used for motor-cars, by reason of the peculiarly trying conditions under which aircraft operate. The demand for an even lighter engine and the necessity for efficient cooling led to the introduction of the rotary air engine, which was first seen at the Rheims Flying Meeting of 1909. This type of engine has been very extensively employed since that time, although some builders still manufacture engines with vertical or sloping

cylinders which more nearly resemble in appearance the engine of the motor-car.

Up to the middle of 1914 the building and flying of aeroplanes had been largely experimental, for while their possibilities had been amply demonstrated, little attempt had been made to put them to practical use. Their use in war had, of course, always been kept well to the front, and our own and other Governments had taken, as has been shown, the liveliest practical interest in every stage of development. The Royal Flying Corps was formed in 1912, and experiments had been carried out in seaplanes and other aircraft in conjunction with the Navy, but little opportunity had arisen to test machines under service conditions until the outbreak of the Great War. The importance of aerial reconnaisance had been long recognized, and during the South African War observation balloons were employed for this purpose. It was obvious that the range of such work would be immensely extended by the use of the aeroplane, and such proved to be the case. Next came the development of aerial photography, and soon it was possible to have a permanent photographic record of the enemy's trenches and positions and to follow his movements and forecast his future line of action by taking photographs at frequent intervals. During the Great War this work was undertaken by all the armies in the field, and naturally fighting between aircraft of the opposing army became common. Small machine guns were fitted and the design of the machine was modified so as to afford protection against the enemy's bullets. The use of aircraft as a means of attack upon positions of importance soon followed, and before the end of the war the new arm had assumed dimensions out of all proportion to its modest application during the early days. This development demanded increased reliability and powers of performance, and large-scale aircraft production. One of the most notable achievements of British engineering is the attainment of this production. Factories, machinery, and man-power were absorbed in the production of other munitions of war, in the maintenance of essential services, and by the fighting forces; material was difficult to obtain; the problems of manufacture were novel and uncertain; yet in spite of all drawbacks the

huge British aircraft industry that existed at the cessation of hostilities had been built up in an incredibly short time. Unlimited demands were made upon the existing makers, and firms whose experience had been gained in other branches of engineering embarked upon aeroplane construction on a large scale. Engine builders increased their plant and their output, with the result that the 100 aeroplanes per annum which had been the output of this country upon the outbreak of war increased to an output of 30,000 in three years, and at the time of the Armistice machines were being manufactured at the rate of 40,000 per annum. Altogether during the period Great Britain manufactured over 50,000 aeroplanes, most of the engines for which were made in this country. In addition, over 80,000 propellers were manufactured. This is an achievement to be proud of under normal conditions, but under the adverse conditions that prevailed at the time its magnitude is greatly enhanced.

Much is expected by some authorities in the future from the dirigible balloon or airship as distinct from the aeroplane. Reference has already been made to the airships of Lebaudy and Santos-Dumont, the latter of which was a tiny ship driven by a 3½ horse-power motor-cycle engine. Further experiments were made with this type of craft in France and Germany, the most important vessels constructed in the latter country being those of Count von Zeppelin. A number of Zeppelin airships were constructed prior to 1914, and although several serious mishaps occurred, some of the vessels made comparatively long voyages and carried a number of passengers. The bombing raids of the Zeppelin airships during the war are unhappily fresh in the minds of most people, but from an engineering point of view these performances show that airships had been developed to a high degree. Several airships, usually of the small non-rigid type, were built in this country at various times by or for the Government. The motive power of the airship, like that of the aeroplane, is the petrol motor, and the balloon is inflated usually with hydrogen. The Germans have recently devoted much attention to gliding, the experimental work being reminiscent of that done by Lilienthal and the Wright brothers. Although the practical future of the glider

may be of little importance except perhaps as a sport, the results of the experiments which were carried out in the late summer of 1922 will probably be useful to the aeroplane designer.

The technical excellence of aircraft is indisputable. Post-war performances such as the flight across the Atlantic by Sir Arthur W. Brown and Sir John Alcock in an aeroplane, and the double journey across the Atlantic in an airship, the R34, demonstrates the extensive radius of operation of aircraft and prove their high degree of reliability. The advantages of air transport are the immense speed which is attained, and the fact that the journey may be made across land or water without transhipment of goods or passengers. Upon the conclusion of the war it was confidently anticipated that, as the means of aerial travel was already at hand, the new mode of transport would rapidly become common, supplementing rail and steamship services, or even becoming a formidable rival. Regular flights between London and Paris and between London and provincial cities were organized; in many cases the aerodromes which were constructed for war-time use were used as depôts for the commercial service, but the initial success with which aerial transport met was short-lived. Air travel is necessarily expensive, and the number of instances in which the saving of time justifies the increased cost is too insignificant at present to supply an adequate support for the elaborate organization which is necessary for the regular operation of air services, so that many of the periodical flights which were organized have been suspended. Even the saving of time is frequently more apparent than real, for as the aerodrome is usually some distance outside a large city, an appreciable amount of time is occupied in conveying the goods to the dispatching aerodrome, and again conveying them from the receiving aerodrome to their destination. This factor is, of course, of greater importance in short journeys than in long ones. The air lines have themselves declared that goods traffic is not economically practicable. In spite of this drawback, the quantity of merchandise that has been conveyed by air amounts in the aggregate to quite an appreciable total. The goods which are so carried are usually articles of light weight and small bulk,

but of considerable value, such as furs, jewellery, precious stones, kinema films, feathers and other expensive articles of millinery. Passenger services have been found to be more remunerative. There are cases where a slight saving of time in personal travel between distant points appears to justify the heavy cost of the hire of an aeroplane; the novelty of the journey is also apparently responsible for the number of long-distance passenger flights which have been made. In another category are the short pleasure flights which have now become a feature at some of the popular holiday resorts, though even this form of passenger travel appears to be waning somewhat in popularity.

The aeroplane has proved itself indispensable in modern warfare, but its application in peace times is at present exceedingly restricted. The visions which were conjured a few years ago of air lines connecting all important points and feeding transatlantic airship lines have not yet materialized. The future of air travel is still largely an unknown quantity, although it undoubtedly has wonderful potentialities.

CHAPTER X

THE AGE OF ELECTRICITY

FROM ancient times the human race has possessed some knowledge of the elements of magnetism and some conception of electricity. The Chinese are supposed to have been familiar with the magnetic compass, and it was known to the Greek philosophers that certain stones had the property of attracting iron. The Greeks knew that when amber was rubbed with wool it became capable of lifting pieces of paper and light bodies. In England our knowledge of both magnetism and electricity is recent. Little was known until the end of the sixteenth century, when Gilbert interpreted to the world some of the underlying principles of magnetic and electric effects. It has been said that "what Shakespeare is to the drama, what Raleigh is to geography, what Spencer is to poetry, what Bacon is to philosophy, that and more than that is Gilbert to the science of electricity." Gilbert was born at Colchester of an old Suffolk family in 1540, and was educated at Cambridge for the medical profession, where great success attended him. In 1599 he was elected President of the Royal College of Physicians. His world-wide reputation, however, was chiefly the result of his experimental studies in magnetism and electricity, on which he is reported to have spent no less than £5,000. There was in his possession a most valuable collection of lodestones and magnetic apparatus. The results of his researches are contained in his famous *De Magnete*, published in 1600, which was greatly admired by Galileo and Kepler. Gilbert, by means of experiment, was able to prove that not only had amber when rubbed a certain property of attraction, but that a large class of bodies, including the diamond and other gems, glass, shellac, resin, and the like, possessed similar properties. To this general class of materials he applied the term "electrics" derived from the Greek word for amber. Gilbert died in 1603, and the character of his work is well

summarized in a passage in Galileo's *Dialogues:* "I highly praise, admire, and envy this author for having formed such stupendous conception of a matter which has been treated by many sublime intellects, but solved by none; he appears to me also to deserve the highest praise for his many and true observations, putting to shame the lying and vain authors who write not only what they know, but also what they hear from the silly crowd, without satisfying themselves by experiment what is true—perhaps, because they do not wish to shorten their books. What I should have desired in Gilbert is that he would have been a little more of a mathematician, and especially well schooled in geometry, the practice of which would have made him less inclined to accept as conclusive proofs what are only arguments in favour of the deductions he draws from his observations. . . . I do not doubt that in the course of time this new science will be perfected by new observations, and by true and cogent demonstrations."* After the death of Gilbert no further progress was made in England in magnetic and electric science for two centuries, until the time of Cumming, Ritchie, Sturgeon, and Faraday.

The greatest contribution to the development of electrical science was made by Michael Faraday. The son of a journeyman blacksmith, he was born on September 22, 1791, and received school education such as the humble circumstances of his family would allow. In 1804, at the age of thirteen, he became an errand boy at Riebau's book-shop, where, after a satisfactory probation period of twelve months, he was accepted as an apprentice to the trade of bookbinding without any premium on account of his exemplary conduct. It was while working in this capacity that he appropriated odd moments at the beginning and end of his day to scan the pages of the books which he was employed in binding. In this way a little book on chemistry by Mrs. Marcet occupied his searching mind—a mind that would not rest content with dogmas set down in any book, but must need substantiate all statements by actual experiment. So the veracity of the author of the book was put to test, for in Faraday's own words he made "such simple experiments in chemistry as could be defrayed in their

* Quoted by Schuster, *Britain's Heritage of Science*, 6.

expense by few pence per week, and also constructed an electrical machine, first with a glass phial, and afterwards with a real cylinder, as well as other electrical apparatus of a corresponding kind." One of the bookseller's customers, Mr. Dance, a member of the Royal Institution, was attracted by the marked intelligence of the embryo scientist, and invited him to hear the last four of a series of public lectures delivered by Sir Humphry Davy at the Royal Institution. The association which Faraday thus acquired with the Royal Institution is recorded in his own words: "When I was a bookseller's apprentice, I was very fond of experiment and very averse to trade. It happened that a gentleman, a member of the Royal Institution, took me to hear some of Sir H. Davy's lectures in Albemarle Street. I took notes, and afterwards wrote them out more fairly in a quarto volume. My desire to escape from Trade, which I thought vicious and selfish, and to enter into the service of Science, which I imagined made its pursuers amiable and liberal, induced me at last to take the bold and simple step of writing to Sir Humphry Davy, expressing my wishes, and a hope that, if an opportunity came in his way, he would favour my views; at the same time, I sent the notes I had taken of his lecture. . . . This took place at the end of the year 1812, and early in 1813 he requested to see me, and told me of the situation of assistant in the Laboratory of the Royal Institution, just then vacant. At the same time that he thus gratified my desires as to scientific employment, he still advised me not to give up the prospects I had before me, telling me that Science was a harsh mistress; and in a pecuniary point of view but poorly rewarding those who devoted themselves to her service. He smiled at my notion of the superior moral feelings of philosophic men, and said he would leave me to the experience of a few years to set me right in the matter. Finally, through his good efforts, I went to the Royal Institution early in March, 1813, as assistant in the laboratory; and in October of the same year went with him abroad as his assistant in experiments and writing. I returned with him in April, 1815, resumed my studies in the Royal Institution, and have, as you know, ever since remained there."* On this

* Schuster, *op. cit.*, 39.

Continental tour Faraday met many of the eminent scientists of that day. The eighteen months thus spent can be regarded as the first period of his life during which he enjoyed a liberal education, and he made every effort to turn it to the fullest account. Upon his return to England, his position and salary at the Royal Institution improved, and he was afforded time and opportunity to devote himself to scientific investigations in the laboratories of the Institution. It was during this period that he evolved his electro-magnetic theory, and demonstrated the possibility of generating electricity by means of magnetic induction, and in so doing laid the foundation on which modern dynamo-electric machine practice is built.

Faraday's work was greatly assisted by the invention, in 1825, of the electro-magnet by William Sturgeon. Sturgeon was born in 1783. He started life as a shoemaker, and later entered the army as artillerist; from here he became a teacher of physics at the Military Academy of the East India Company, and while engaged in the latter capacity resided at Woolwich. He spent the last twelve years of his life in carrying out scientific investigations in Manchester. While in London he founded the short-lived Electrical Society of London, and edited *Annals of Electricity*. Sturgeon found that by winding a coil of wire round a rod or horse-shoe of soft iron, and then connecting the coil by wires to an electric circuit which conveyed electric current from a battery so that the current circulated round the iron, the iron core became a powerful magnet, but continued only so long as the electric current was permitted to circulate. On stopping the current by opening the circuit, the soft iron core ceased to attract. On reclosing the circuit the iron core again became magnetized. Hence, therefore, Sturgeon provided a method of manufacturing magnets the operation of which could be controlled at will.

Faraday's dynamo consisted of a copper disc made to rotate in a magnetic field produced by an electro-magnet designed after Sturgeon's invention. The disc had one spring contact pressing against its axis and another against the perimeter, and these being connected to a galvanometer, it was found that a current flowed so long as the disc rotated. This experimental dynamo was the basis of all subsequent experiments in this

type of machine. Tyndall says of this feat that it was the Mont Blanc of all Faraday's achievements. "Thus was born into the world the first rudimentary dynamo or machine for generating electric current merely by the mechanical motion of a copper conductor in a magnetic field."* In 1841 Faraday suffered a breakdown in health, but after a Continental holiday of long duration he returned to his work at the Royal Institution in November, 1845. It was from this time onwards that many of his most valuable discoveries were made. It is impossible to record in these pages the many contributions which Faraday made to the science of electricity; it must suffice to say that it is only by his epoch-making discoveries of fundamental facts that the rapid progress of electrical engineering has been possible. From this point onwards the applications of the science of electricity began to be explored, and its commercial possibilities to be realized. The work of Faraday heralded the arrival of the Age of Electricity, which, while following the Age of Steam, did not displace its power, but rather turned it to more useful account. With the introduction of the steam engine began the taste, the fashion, and the general use of travel, the growth of markets dependent upon the rapid transportation of goods, and the establishment of national and international postage. The progress of this development has been greatly hastened, and its extension widened, by the power of electricity added to the power of steam.

It will be convenient to follow the various applications of electricity in the order in which they became of commercial importance, and of these the electric telegraph is the earliest.

I.—Telegraphs, Telephones, and Radio Communication

Although the possibility of the electric telegraph appears to have been perceived even as early as the eighteenth century, notably by Charles Marshall in 1753, it was not until Francis Ronalds, about 1840, enquired into the advantages of electricity for communication purposes that it received public attention in this country. "Ronalds was the son of a London merchant; his method of transmitting signals consisted in charging and

* Fleming, *Fifty Years of Electricity*, 44.

discharging an electroscope through a long wire. In his experiments he used a length of eight miles of wire, properly insulated and embedded in the soil of a garden in Hammersmith. The distinguishing feature of his apparatus consisted in an arrangement founded on the same principle as the one so successfully employed in the type-printing arrangement invented at a much later date by Hughes. Two discs bearing the letters of the alphabet near their circumference were made to rotate with the same speed at the two ends of the line. The electroscope placed at the receiving end was discharged from the sending end. The sender watched the moment when the required letter passed a certain position, and the same letter passing the corresponding position at the receiving end at the moment of discharge could therefore be read off. The two discs were adjusted by means of a signal before the message was sent, and it only remained to ensure that the discs rotated synchronously during the time it took to send the message. Bits of the original wire with its insulating covering were dug out later, and are now preserved in the Science Museum at South Kensington."* Ronalds submitted to the Government in 1816 this design of telegraph, but met with no response, except the discouraging reply from the Secretary of the Admiralty that "telegraphs of any other kind are now totally unnecessary, and that no other than the one now in use will be adopted."† The Admiralty's reply refers to the semaphore in use at the conclusion of the French War.

A new experimenter entered the field in the person of William Fothergill Cooke, the son of a Durham physician, who also during his early days prepared to enter the medical profession. While pursuing his medical studies at Heidelberg, Cooke became keenly interested in the problem of the telegraph, withdrew from his studies, and returned to England, where he endeavoured to give practical application to his ideas on the telegraph. He constructed an apparatus, which he offered in January, 1837, to the Liverpool and Manchester Railway authorities, primarily with a view to its use in the Lime Street tunnel, but his offer was refused. During this period Professor Charles Wheatstone, of King's College, London, was investigating the properties of

* Schuster, *op. cit.*, 188.

† Quoted by Schuster, 188.

the electric current, and was closely interested in its application to the telegraph. Cooke and Wheatstone were brought together and evolved a working partnership, and their first joint patents were taken out in 1837 for improvements in signals and alarms at distant places by means of electric currents transmitted through metallic circuits. On June 25 of the same year Cooke and Wheatstone communicated with each other by means of electric signals over a wire between Euston Station and Camden Town on the then London and Birmingham Railway. In 1843 the first public electric telegraph line under the patent of Wheatstone and Cooke was installed between Paddington Station and Slough; this line early came into notice on account of the service it rendered in facilitating the capture of an escaping murderer.* The first telegraphic codes adopted necessitated the use of a large number of wires to transmit the various letters of the alphabet, and through an accident the operators discovered that the line could be worked quite efficiently with a much smaller number of wires. The difficulties in this connection were further reduced by the introduction of the greatly improved Morse code; the first code as devised by Wheatstone and Cooke continued to be used for a considerable period in English telegraph working.

The early telegraphs were worked by the Electric Telegraph Company, formed in 1846, which undertook the maintenance

* During the early days of its development, the telegraph aroused no small amount of curiosity. Extraordinary stories of its mode of operation were circulated, and it was even believed that articles could be "telegraphed" by actual transmission along the wires. Many amusing incidents are recorded at this period. "A railway guard once noticed an umbrella lying on the platform at one of the stations, and picking it up, he put it in his van, waiting till someone enquired for it. At the next stopping-place an old lady began very excitedly enquiring if anyone had seen her umbrella. Asking a friend to hook the article in question upon the wires, the guard said to the old lady: 'We will telegraph and see if you have left it behind.' Taking her into the office, he began moving the handles and ringing the bell, and then told her to go outside and she would find the missing article on the wires, forwarded by electricity. The old lady was delighted at seeing her treasure again, and asked in her native Irish accent: 'Faith, and how did the poor cratur pass by the posts without even a scratch or a mark on it, poor soul?' The guard replied: 'Ah, ma'am, if I were to try and explain to you, you would not be able to understand it. We have queer things in this country.' 'And sure enough you have,' rejoined the old lady; 'and if the inventor of that thing don't go to heaven, nobody ought.' So she departed, duly impressed with the possibilities of the electric telegraph."

of the railway telegraphs and granted no facilities to the general public. Its charges were 1s. for twenty words within a radius of 50 miles, 1s. 6d. within 100 miles, and 5s. if exceeding 100 miles. The company, however, was not a commercial success. Telegraphic money orders were established in 1850, and numerous companies were formed which worked independently of the railway telegraphs and provided facilities for the general public. The resulting competition substantially reduced telegraphic charges, which brought about an increased demand. From 1855 to 1868 the number of messages carried annually by all the telegraph companies of the United Kingdom increased from 1,017,529 to 5,718,989. At the same time the average receipt per message obtained by the Electric Telegraph Company was reduced from 4s. 1½d. to 2s. 0¾d. The exploitation of the telegraph by private companies was not an unmixed blessing, as they were primarily concerned with making profit and not with catering for the varied needs of the public, and before long there was considerable agitation for the acquisition of the whole telegraph system by the Government. The Edinburgh Chamber of Commerce were the leaders in this campaign, and they were shortly afterwards followed by many other Chambers of Commerce, while all sections of the public press actively participated in the campaign. In 1865 the Government authorized an enquiry to be made respecting the feasibility of acquiring all the telegraphic interests of the country, and it was found that an exceedingly small number of towns, etc., were served with the telegraph as compared with postal services, the figures being 2,800 places with telegraphic facilities, against 10,000 places enjoying postal services. Finally a Bill came before Parliament, introduced by Mr. Scudamore, who contended that "the charges made by the telegraph companies were too high and tended to check the growth of telegraph; and there were frequent delays of messages; that many important districts were not provided with facilities; that in many cases the telegraph office was inconveniently remote from the centre of business, and was open for too small a portion of the day; that there was little or no improvement, so long as the working of the telegraphs was conducted by commercial companies, striving to earn dividends and engaged

in wasteful competition with each other; that the growth of telegraphy had been greatly stimulated in Belgium and Switzerland by the annexation of the telegraphs to the Post Office of these countries, and the consequent adoption of low charges, and that in Great Britain like results would follow the adoption of like means, and that the association of the telegraph with the Post Office would produce great advantage to the public and ultimately a large revenue to the State." The State finally took over the telegraphs on the basis of a twenty years' purchase of the profits of the year ending June 30, 1868. The Chancellor of the Exchequer described the terms as "very liberal but not more liberal than they should be under the circumstances." The telegraphs were finally transferred to the Post Office on February 5, 1870. The increased volume of telegraph business that was anticipated from the reduction of rates was fully realized, so much so that whereas 6,500,000 messages were transmitted in 1869, the number rose to 10,000,000 in 1871, and to 20,000,000 in 1875.

The acquisition of the telegraphs by the Government has been followed by marked improvements not only in the technical details and construction of the apparatus and its operation, but in the great extension of facilities afforded to the general public for using the telegraph. An improvement of outstanding importance has been the increased speed with which messages can be transmitted. "In the case of ordinary hand signalled messages the speed at which the words can be transmitted per minute depends upon the skill of the manipulator of the transmitting key, and on the rate at which the receiving clerk can read the signals by eye or ear. This does not generally exceed 35 words, or 150 letters per minute, and it taxes endurance to keep this up long together."* Increased speed was obtained by the invention of the automatic transmitter whereby "the message to be transmitted is first translated into a set of signs represented by holes punched in a strip of paper tape. In the case of a long message the various paragraphs can be so punched simultaneously by different operators on separate tapes. These tapes are fed in proper order through a machine called the transmitter, which sends corresponding electric currents into

* Fleming, *op. cit.*, 50.

the line, and they are recorded at the receiving end by a Morse printer. By such methods speeds of 200-400 words per minute can be sent and received."* During recent years telegraphic machines resembling typewriters have been invented, in which the keys represent letters, and on depression cause holes to be punched in the tape, which latter is then fed into an automatic transmitter described above. "The future of inland telegraphy is bound up with the improvement and simplification of machine telegraphy, and a telegraphic instrument of the future may be said to be a kind of typewriter split into two parts—*i.e.*, a keyboard at the transmitting station, and a page-printing receiver at the receiving station, the two being connected by a wire through which combinations of positive and negative electric currents are being rapidly sent for each letter transmitted."†

Shortly after the establishment of the land telegraph as a sound practical proposition, engineers began to explore the possibilities of laying telegraph cables under water so as to link up the continents. The idea of submarine telegraphy was suggested by Wheatstone in 1840, but nothing even of an experimental character was undertaken until 1845, when an investigator named West laid a short cable in the Solent. This cable was protected from the water by a covering of india-rubber, but it proved far from satisfactory as an insulating material, and presented the type of trouble which was experienced with all the early cables. Real advancement in submarine telegraphy took place only when the discovery of gutta-percha provided a material possessing marked water-resisting properties and greater mechanical strength than india-rubber and one that could be readily applied to the outside of a round cable. The first practical application of the submarine telegraph was carried out by Mr. Brett and his brother. Brett obtained the sanction of Louis Philippe to lay a cable between France and England, but the project failed. In 1849 he again approached the French authorities, and was granted permission provided communication was established before September, 1850. Funds were raised, a temporary cable laid, and communication established, but its success was of short duration.

* *Ibid.* † *Ibid.*, 70.

The gutta-percha, while excellent as an insulating material from an electrical point of view, and mechanically stronger than india-rubber, was nevertheless not strong enough to withstand the constant rubbing action against the rocks caused by the tides, and on this account the cable failed. About this time Brett was assisted by a well-known engineer of that day named Crampton, who had it suggested to him that the cable might be protected against rubbing and cutting action by the rocks by wrapping it with galvanized iron wire, and a cable of this construction was laid between Dover and Calais in 1851. This was the first commercially successful submarine cable, and definitely established the practical possibility and utility of submarine telegraphy; and it was not long before other similar cables were laid. In 1852 a line was laid between Holyhead and Howth, near Dublin, and in 1853 one between Dover and Ostend, and in the same year a cable 120 miles long from England to Holland. By the close of the year 1857 there were as many as thirty-seven submarine cables, having a total length of 3,700 miles.

Nearly all these lines were laid in the North Sea and the Irish Sea, but a cable from Europe to America had already been projected by Mr. C. W. Field, an American merchant, who formed a company called the New York, Newfoundland, and London Telegraph Company, and obtained in April, 1854, a Charter from the Newfoundland Government. The scheme was put into operation by the laying of the overland part from Newfoundland to Nova Scotia. In the summer of 1856 the company chartered a steamer, and the laying of the trans-Atlantic cable was begun. This cable broke when about half-way across. In this country the subject of the Atlantic cable engaged the attention of the Magnetic Telegraph Company and its engineer, Mr. (afterwards Sir) Charles Bright. Field visited England in 1856, and together with Bright and the brothers Brett formed a company for the purpose of establishing telegraphic communication between this country and America. The Atlantic Telegraph Company was registered in 1856, with a capital of £350,000, part of which was obtained from the proceeds of a series of lectures delivered in the principal cities. Bright was appointed engineer and Whitehouse electrician to

the company. To ensure that the cable would be a paying proposition the English Government was approached, and they promised to send messages to the value of £14,000 per year. In 1857 a suitable route was arranged and two ships, one the *Niagara*, supplied by the American Government, and the other the *Agamemnon*, supplied by the English Government, commenced the laying of the cable. The laying of the first half of the cable was entrusted to the *Niagara*, and its shore end was laid in Valencia Harbour, Ireland, in August, 1857. During the first few days of the laying of the cable satisfactory progress was made, but after 380 miles had been laid, a misapplication of the brakes on the paying-out gear occurred and caused the cable to snap. This took place on August 11, when the ships returned to Plymouth with the remainder of the cable. In the next year a fresh attempt was made to lay cable, when every possible precaution was taken and means for lessening the friction on the cable were devised. Instead of commencing at Ireland and laying the cable in one length, the two ships proceeded to mid-ocean, where the ends of the cable from each ship were joined, and the ships proceeded one for America and one for England. This second attempt was also unsuccessful, as several breaks in the cable occurred, and the ships returned to Ireland. The third attempt was commenced in July, 1858, when the ships sailed from Queenstown, and met in mid-ocean on July 29, on which date the two cables were spliced and paying-out commenced. This time the work proved successful, and the shore ends were made fast on August 5. On the 16th of the month communication across the Atlantic was established, but later, owing to a mistake in the method of electrically operating the cable, the insulation was damaged, and the cable ceased to operate after October 20. The next attempt to lay an Atlantic cable was made in 1865, and for this purpose the famous vessel the *Great Eastern*, designed by Brunel, was reconditioned after a short and luckless career as an ocean carrier, to accommodate the cable and carry out the laying. The *Great Eastern*, laden with the cable, commenced her voyage from Valencia at the beginning of July, 1865, and after numerous faults had occurred, and when nearly 1.′ miles had been laid, the cable broke. After several unsu′

attempts to recover the lost cable end the *Great Eastern* finally returned to England.

The Anglo-American Telegraph Company replaced the Atlantic Telegraph Company, and under the direction of the former another attempt was made in the following year, 1866. The *Great Eastern* was again used, and not only did she carry cable for an entirely new line across the Atlantic, but also additional cable to complete the 1865 line. The *Great Eastern* left Ireland on July 13, and landed in Trinity Bay, Newfoundland, a fortnight later, after having successfully laid the new cable. She then returned to mid-ocean to grapple for the lost 1865 cable, and her success is a great tribute to the skill of the navigator Moriarty. An account of the achievement is given by Mr. Cyrus Field. "Many don't understand it, and every day I am asked how it was done. It does seem rather difficult to fish for a jewel at the bottom of the ocean, two and a half miles deep. But it is not so very difficult when you know how. It was the triumph of the highest nautical and engineering skill. Having taken our bearings, we stood off three or four miles so as to come to broadside on, and then casting over the grapnel, drifted slowly down upon it, dragging the bottom of the ocean as we went. At first it was a little awkward to fish in such deep water, but our men got used to it and soon could cast a grapnel as straight as an old whaler throws a harpoon. Our fishing line was of formidable size. It was made of rope twisted with wires of steel, so as to bear a strain of thirty tons. It took about two hours for the grapnel to reach the bottom, but we could tell when it struck. I often went to the bow, and could feel by the quiver that the grapnel was dragging on the bottom, two miles under us. But it was very slow business. We had storms and calms, fogs and squalls. Still we worked day after day. Once, on August 17th, we got the cable up and had it in full sight for five minutes—a long, slimy monster, fresh from the ooze of the ocean's bed—but our men began to cheer so wildly that it seemed to be frightened and suddenly broke away and went down into the sea. This accident kept us at work two weeks longer, but finally on the last night of August we caught it. We had cast the grapnel thirty times. It was a little before

midnight on Friday that we hooked the cable, and it was a little after midnight (Sunday morning) when we got it on board. What was the anxiety of those twenty-six hours! The strain on every man's life was like the strain on the cable itself. When finally it appeared it was midnight; the lights of the ship and in the boats around our bows, as they flashed in the faces of the men, showed them to be eagerly watching for the cable to appear in the water. At length it was brought to the surface. All who were allowed to approach crowded to see it. Yet not a word was spoken; only the voices of the officers in command were heard giving orders. All felt as if life and death hung upon that issue. It was only when it was brought over the bow and on the deck that men dared to breathe. Even then they hardly believed their eyes. Some crept towards it to feel it, to be sure it was really there. Then we carried it along to the electrician's room to see if our long-sought-for treasure were alive or dead. A few moments of suspense, and a flash told of the lightning current set free. Then did the feeling long pent-up burst forth. Some turned away their heads and wept, others broke into cheers; and the cry ran from man to man, and was heard in the engine room, below deck, and from the boats on the water and the other ships; while rockets lighted up the darkness of the sea. Then with thankful hearts we turned our faces again to the west. But soon the wind rose, and for thirty-six hours we were exposed to all the dangers of a storm on the Atlantic. Yet in the very height and fury of that gale, as I sat in the electrician's room, a flash of light, a message, came up from the deep, which had crossed to Ireland, and come back to me in mid-ocean, telling that those so dear to me whom I had left on the banks of the Hudson were well and following us with their wishes and prayers. This was like a whisper of God from the sea, bidding me keep heart and hope. The *Great Eastern* bore herself bravely through the storm, as if she knew that the vital cord which was to join two hemispheres hung at her stern; and so on Saturday, September 7th, we brought our second cable safely to shore." The 1865 and 1866 cables were short-lived, and broke down in 1877 and 1872 respectively, but by 1877 the Atlantic cable service had been augmented by

the laying of four other cables, including one from France. "In 1869 cable communication was established with Egypt; in 1870 with India, Malaya, and Java; in 1871 with Cochin China, Hong Kong, and Australia; in 1874 with South America; in 1876, New Zealand; in 1879, South Africa."* In 1877 Sir Charles Bright stated that 107,000 miles of submarine cable had been laid; and ten years later half as much again was laid, representing in all a capital expenditure of £42,000,000, 75 per cent. of which had been provided by this country. The manufacture, laying and maintenance of the submarine telegraph cables has developed into an important industry, and it is noteworthy that the great majority of the submarine cables of the world have been manufactured in Britain. "Among the men of business it was undoubtedly Sir John Pender, 1815-1869, who contributed most to the development of this colossal industry, and to his unfailing faith in its ultimate realization must be ascribed the completion of the first successful Atlantic cables."† The 1869 Telegraph Act, which conferred a telegraph monopoly upon the Government, did not relate to submarine telegraphs, which continued, with but a few exceptions, to be controlled by private companies.

"Submarine cables have played a useful part in war. In 1882, during the bombardment of Alexandria, the cables were taken on board a repairing ship and communication then established with London. During the Pendjek controversy with Russia, in 1885, a cable laid from the naval base at Port Hamilton to the mouth of the Yangtzse enabled the British Fleet to effect communications. An additional submarine cable was laid during the South African War to maintain communication with London. During the Great European War, 1914-1918, all the allied and neutral fronts were served by submarine cables, and communications were continuously maintained. However much the commercial and social traffic might be delayed, the urgent war communications were assured. Various strategic cables were laid, concerning which details are unnecessary. Repairs to cables which normally employ a

* Judd, "Submarine Telegraphy," *Journal of the Institution of Electrical Engineers*, 1922, LX. 406.

† *Encyclopædia Britannica*, "Atlantic Telegraphs."

fleet of vessels were naturally obstructed; but at great risk and with an immunity from casualty which is an outstanding tribute to the efficiency of the Admiralty Intelligence Department, the necessary repairs were carried out. . . . The little vessel charged with maintaining the cables around Gallipoli, whose operations were almost incessant, worked frequently under fire but escaped without casualty."*

The next development in electrical means of communication was the telephone, which in the comparatively short space of forty years has become universally used. The early work connected with the telephone was carried out in the United States, notably by Professor Graham Bell and Thomas Edison. The part which Bell took in the development of the telephone is well described by Dr. J. A. Fleming: "Although several persons had some vague ideas of the possibility of transmitting articulate speech electrically from place to place, the verdict of courts of law, after the most searching enquiry, is that the inventor of the speaking telephone was Alexander Graham Bell. The telephone differs from the telegraph, not only by the fact that it transmits articulate sounds and not merely signals which have to be interpreted, or else printed letters, but in respect of the fact that the telephone is much more the product of a single inventive mind than the telegraph. Alexander Graham Bell was the son of Alexander Melville Bell, who was at one time lecturer on elocution in University College, London. Mr. Bell, senior, went to reside in Canada in 1870, taking his sons with him, and he was the author of a very original treatise on visible speech. Alexander Graham Bell, his celebrated son, had therefore his attention directed to phonetics, acoustics, and music from an early age. Before long an idea rose in his mind of inventing a form of multiple telegraphy which depended upon the electrical transmission of musical tones along a telegraph wire. His early experiments on this subject led him to a more important conception—viz., that of transmitting articulate speech electrically along a wire. This he saw involved the creation and transmission along a telegraph wire of an undulating electric current, the strength of which should vary just as the air pressure varies at any point in the air

* Judd, *op. cit.*, 407.

when a speech wave passes that point. The question then arose as to how to produce such a current by speech and cause it to recreate speech sounds at a distant place. After prolonged experiment Bell arrived at last at the simplest possible solution of this problem. A thin disc of iron was fixed near to the pole of a permanent magnet, and the polar end near the plate was surrounded by a coil of insulated wire. Exactly similar implements were placed at the two intercommunicating stations and the wires of their magnet coils connected by a double line wire or by a single wire and an earth return. When articulate speech is made against one iron disc it is set in vibration by the changing air pressure and this motion creates an induced electric current in the coil wound on the adjacent magnet. This varying current flows through the line wire and strengthens or weakens the magnet pole near the iron disc at the receiving station, and its varying attraction sets in vibration the iron diaphragm and thus reproduces the speech sounds. The beauty of the invention consisted in the fact that identical instruments act both as generator of these variable or undulatory currents and also as receiver. They change energy of air vibrations into energy of electric currents, and then effect the reverse transformation and reproduce the air vibrations, and therefore speech, at a distant station. Bell was the first to effect this transformation. He obtained, in the United States, a patent, No. 174465, March 7th, 1876, which proved to be a master patent. This patent and the corresponding British patent, No. 4765, of December 9th, 1878, had to pass through the fire of much litigation, and a certain disclaimer was made in 1878, but it emerged triumphant from all ordeals. In the year 1876 an international exhibition was held in Philadelphia, U.S.A., called the Centennial, and Bell's telephones were there exhibited in action. Lord Kelvin and Professor Joseph Henry were judges of the electrical exhibit, and Lord Kelvin was immensely enthusiastic over Bell's invention, and expressed himself in a report most eulogistically. He brought away with him to England one form of Bell telephone receiver, and exhibited and described it to Section A of the British Association, which met the same year in August, at Glasgow. The author of this book was present on that occasion and

heard Lord Kelvin describe in Section A how he had heard articulate speech transmitted over an electric wire for the first time. He said: 'With my ear pressed against this (iron) disc I heard it speak distinctly several sentences first of simple monosyllables, "To be or not to be" (marvellously distinct). Afterwards sentences from a newspaper, "S.S. *Cox* has arrived." I failed to hear the "S.S. *Cox*," but the "has arrived" I heard with perfect distinctness, then "the Americans in London have made arrangements to celebrate the 4th July." I need scarcely say I was astonished and delighted.' "*

It was not until a year later—at the British Association meeting in Plymouth in 1877—that the first working telephones were exhibited in England. They had been brought from America by Mr. Preece, who gave a demonstration of their use. The first important development of the telephone in this country was made in 1878 by Professor D. E. Hughes, who perfected the telephone receiver and transmitter, and constructed these in the form in which they are now commonly used. From this point onwards for a number of years the energies of telephone engineers were directed towards securing an ever-widening field of application for the telephone. During the years 1876-1877 licences were granted for the use in this country of the Bell and Edison telephone patents, and companies were formed to work these patents. The Edison Telephone Company was formed in London in 1879; the year after the Telephone Company was formed to acquire the Bell rights. These companies were primarily concerned with the supply of private telephones—*i.e.*, lines permanently connected between any two given places; the idea of public facilities whereby a large number of subscribers could communicate with each other had not yet been considered. After these companies had unsuccessfully offered their patents to the Government, the Edison Company declared its intention of starting business in London on public lines, which resulted in the Government instituting proceedings against the Edison Company for infringement under the Telegraph Act, 1869. By this Act the Government enjoyed a monopoly of all schemes and devices for electrical communication with the one exception

* Fleming, *op. cit.*, 80.

of safety telegraphs between signal boxes on railways. In the lawsuit which followed the position of the Government was established, and it was held that electrical communication schemes could only be carried out by the Postmaster-General, or with his permission. At this juncture the Bell and Edison Telephone Companies amalgamated and became the United Telephone Company, and received a licence from the Government which required that payment should be made of a royalty of 10 per cent. on the gross revenue of the company. When these licences were first issued they were of a very restricted character, and forbade "the erection of poles or wires on, or to place wires under, any highway or private property." The licensee could "not erect public call offices or lay trunk lines from one town to another." Public agitation against these restrictions became so strong that they were removed in 1884, when the licensee was allowed to erect public call offices and trunk lines; but permission for wayleaves in the public streets was still refused.

To strengthen the position of the private telephone companies and to effect economies, the various private enterprises amalgamated in 1889 to form the National Telephone Company, which continued to hold the monopoly until 1911, when it was taken over by the Post Office. Some idea of the expansion of the telephone service of the kingdom under the National Telephone Company may be gleaned from the following statement: "In 1906 there were 30,551, equal to 7·2%, more telephone stations in the United Kingdom than in the ten European countries of Austria Hungary, Belgium, Denmark, Holland, Italy, Norway, Portugal, Russia, Sweden and Switzerland, having a combined population of 288 millions as against a population of 42 millions in the United Kingdom. Apart from France, Germany and Switzerland, there was no country in Europe that had as many telephones working as London. That city, with a population of 6 millions, had nearly as many telephones as the whole of Sweden with about the same population, or as the whole of France with a population of 39 millions. The only European country which can be compared with the United Kingdom in telephone development is Germany. With a population of 58 millions, there are 10·2 telephones per 1,000

of the population in that country, compared with 10·15 in Great Britain and Ireland."*

A recent development in telephony has been the introduction of automatic exchanges. Under the ordinary telephone system subscribers' lines are brought together at exchanges where the operators, who are usually girls, carry out the work of connecting subscribers as required. Under the automatic telephone system the human operation at the exchange is dispensed with and replaced by an electrically operated selective device. Up to the end of the year 1921 twenty automatic exchanges had been installed by the General Post Office in the provinces, the largest being at Leeds, which provides for 7,000 lines at present and an ultimate capacity of 15,000 lines. A beginning has now been made with automatic exchanges in London, where a section of 3,000 to 4,000 lines is in course of construction. The mechanism required for the automatic exchanges is very complicated, but this has been worked out in full detail in various ways by different firms, who now provide complete equipment for automatic exchanges.

Developments have also taken place in long-distance telephony, but in this work technical difficulties arise which are negligible on short lines. These difficulties arise by reason of "distortion" which takes place in the character of an electric current when transmitted through a cable over long distances, and which results in the case of the telephone in speech transmitted at one end being very indistinct at the other, or receiving, end of the line. Two methods have been devised for overcoming this difficulty. The first method, which was strongly advocated by Mr. Oliver Heaviside, the eminent mathematician, thirty-five years ago, but which has only recently been applied in this country, consists in "loading" the line with specially constructed coils. This device renders the line very expensive, and the London to Glasgow trunk line provides an example of this method. This line, 400 miles in length, weighs 1,600 pounds per mile, and hence contains a total of 300 tons of copper wire, representing an outlay of £30,000 for copper alone. The second method of working long-distance telephone lines involves the use of a delicate piece of apparatus invented by

* *Encyclopædia Britannica,* "Telephones."

Dr. J. A. Fleming, of the University of London, and known as the "thermionic valve." This apparatus resembles an incandescent electric lamp comprising a glass bulb which is highly exhausted of its air and containing a filament of tungsten wire which can be rendered intensely hot by an electric current passing through it. It differs, however, from an electric lamp by having the filament surrounded by a metal cylinder. This device has the property of permitting the introduction of new electric impulses into a circuit when the strength of the original impulses is nearly exhausted. Hence when this valve is applied at intervals in a long-distance line it brings back the original volume of sound, and the process can be repeated indefinitely. Recently these valves have been used in a new trunk line which the General Post Office has installed between Manchester and London. This cable, placed underground, contains a sufficient number of wires to permit of 240 conversations taking place simultaneously without any confusion.

The next epoch in electrical communication is marked by the introduction of wireless telegraphy and telephony. The first idea of wireless communication was to use the earth or sea as a conductor of electrical impulses. This method was suggested by James Bowman Lindsay, "a self-taught genius," of Dundee, in 1845, but on account of the very weak electric currents involved and the lack of sufficiently sensitive apparatus to detect them, this means of communication made little progress until the invention of the telephone. On account of the sensitivity of this instrument progress in wireless telegraphy, through the medium of the sea and the earth, was made possible, and Trowbridge in 1880, and Sir William Preece in 1886 and 1887, carried out several successful experiments. This method of communication was turned to account during the European War of 1914-1918. Land forces were able to communicate over short distances by sinking plates in the earth at the two places, and using the intervening earth as a conductor, and this device was adopted where the erection of aerials for radio-telegraphy was impracticable.

Another method of wireless telegraphy, first investigated by Sir Oliver Lodge in 1898, and also applied during the war, involved the principle that an alternating electric current

flowing in one wire produced a second current in an adjacent wire. By this method ships were enabled to ply their way safely through minefields. "The ship to be guided is provided with two coils of insulated wire placed one on the port and the other on the starboard side below the water line. An insulated cable is laid at the sea or river bottom, and the far end is connected to a metal plate laid in the water. An alternating current is sent through the cable from a generator placed on shore, and this current flows through the cable and enters the water by the plate, and then returns through the earth. If a telephone be inserted in each of these coils sounds will be heard in it as long as the ship steers along and near to the cable. If the ship deviates from the course the sounds become fainter or vanish in one or both telephones. Hence a ship can by this means feel its way along the cable into a harbour or up a river."*

These methods of wireless telegraphy are useful, but their field of application is distinctly limited compared with the modern form in which wireless telegraphy is applied, and which only dates from the last ten years of the nineteenth century. The underlying principle of this modern method may be illustrated by the example of a stone, thrown in the centre of a pond, sending out ripples in every direction, which will cause a cork, floating anywhere in the pond, to bob up and down in the same spot. In the same way a suitable electrical disturbance sends out electrical waves which may be detected by the oscillations they cause in a suitable receiving circuit. Although during the latter part of the nineteenth century several British scientists conducted experimental research relating to radio-telegraphy, notably Clerk Maxwell, Sir Oliver Lodge, Professor D. E. Hughes, and Admiral Sir Henry Jackson, there can be little doubt that credit for establishing wireless telegraphy on a practicable and commercial basis rightly belongs to Senator G. Marconi, whose inventions in 1895 made long-distance wireless telegraphy possible. Marconi conducted his original experiments in 1895 on his father's estate near Bologna, Italy, and in the following year came to England, where, after covering his invention by English patent,

* Fleming, *op. cit.*, 309.

he brought it to the notice of Sir William Preece, then Chief Engineer of the Post Office Telegraphs. In 1898 he constructed two wireless stations, one on the Isle of Wight, and the other at Bournemouth, about 12 miles apart. Lord Kelvin was invited to send messages from these stations, and it is of interest to observe that with his characteristic enthusiasm he insisted on paying for them at postal rates, as a proof of his conviction that the new system of communication had reached a commercial stage. At Easter, 1899, Marconi succeeded in transmitting wireless messages across the English Channel, and his success attracted considerable public attention. In August of the same year extensive experiments in wireless telegraphy were conducted by the British Navy, and the two cruisers *Juno* and *Europa* were fitted with wireless apparatus. Public attention was further stimulated, when on April 28, 1899, the s.s. *R. F. Mathews* ran into the East Goodwin Lightship, which had just been equipped with wireless apparatus. Although considerable damage was done, the lightship was able instantly to communicate with the South Foreland Lighthouse and obtain assistance.

Marconi's first long-distance transmitting station was erected at Poldhu in Cornwall in October, 1900, his object being to endeavour to bridge the Atlantic with wireless messages. When this station was completed, Marconi proceeded to Newfoundland in November, 1901, and stationed himself at St. John's. By means of kites and balloons he raised a temporary aerial wire, and after initial difficulties were overcome he succeeded in receiving signals transmitted from Cornwall. From this point onwards improvements have taken place continuously, mainly in the design of apparatus and in speeding up the signalling, so as to make commercial work possible. The Marconi Company opened a large number of radio stations throughout the country; ships in large numbers, including those of all the principal navies of the world, were equipped with wireless apparatus, and communication over 300 to 400 miles was readily established. Informal conferences were held in Berlin in 1903 and 1906, and in London in 1912, and here various regulations for the proper control of wireless communication were proposed, and later confirmed by the

main countries of the world, so that a code of law became established for the proper ordering of the new means of communication. The various radio stations constructed by the Marconi Company were purchased by the General Post Office in 1910, and from that date onwards it became possible to send radio messages to ships at sea from any Post Office in the country. During the past twenty years many inventions have been made in radio-telegraphy, the majority of which have extended the range of transmission of wireless messages. Perhaps the most important of these inventions was the thermionic valve, invented by Dr. J. A. Fleming in 1904. The character of this device has already been described in connection with the telephone, but it has a perhaps more important field of application in radio-telegraphy as a generator of high-frequency oscillations. By its means regular messages are being sent to Australia; the first such message was transmitted on September 22, 1918, from the Marconi Carnarvon Station to Sydney, a distance of 12,000 miles. The message was largely of an experimental character, and it is only during the last year that a high-power valve transmitting station has been installed at Carnarvon, which now works successfully with Australia.

Although the art of radio communication is of so recent date, it has already rendered invaluable assistance to humanity, and has been instrumental in saving a great number of lives in case of collision, fire at sea, and in shipwreck. All the passengers and crew were rescued in the collision between the White Star liner s.s. *Republic* and the s.s. *Florida*, in 1909. The toll of life in the *Titanic* tragedy on April 4, 1912, was not as great as it might have been owing to the service rendered by its radio apparatus. The s.s. *Carpathia*, at a distance of 70 miles, picked up the *Titanic's* call for help, and though late on the scene, was able to rescue 711 persons, who otherwise would surely have perished with the 1,513 who went down. Another service rendered by radio is in making a daily newspaper possible on board the ocean liners. The *Cunard Daily Bulletin*, first published on the R.M.S. *Campania* in 1904, and giving the main news items of the day, is typical of this daily news service.

The latest development in radio communication is the radio transmission of articulate speech, as radio-telephony, which differs from radio-telegraphy in the use of a telephone instead of a Morse key to control the electric radiations. Communication by this method took place across the Atlantic for the first time in March, 1919, by the Marconi Company, between Ballybunion, in the county of Kerry, and Louisberg, in Nova Scotia, a distance of 2,000 miles. The tests there carried out showed that radio-telephonic speech between London and New York is a commercial possibility, and as soon as a demand from the commercial world arises the practice can be established. By this means also telephonic communication between aeroplanes in flight is possible, and has been carried out between machines 50 miles apart. During the past year radio-telephony in this country has entered a new stage of development which promises to have enormous social influence. Under the control of the Postmaster-General, items of news, musical programmes, speeches, lectures, and other matters of public interest are now transmitted or "broadcasted" from a number of large central broadcasting stations, which are operated by the British Broadcasting Company. At the same time radio receiving apparatus is sold to the general public at prices which place it within the reach of all, and on payment of a small licence to the Postmaster-General the subscribers can use their receiving sets to "listen in" to concerts, etc., transmitted from the broadcasting stations. Such are the present applications of radio communication, which has finally resulted in no two parts of the world being separated by a space, measured in time, of more than one-fifth of a second.

II.—Electric Traction

Although street tramways originated in America, they were introduced into this country soon after their invention. An American named George Francis Train, in 1850, constructed at Birkenhead the first street tramway in England. Other lines quickly followed, although several constructed in London without authority were condemned as being a hindrance to other forms of traffic. It was, however, the tramway system conducted in Liverpool in 1868 that first attracted public

interest, and earned for the system the popularity it has ever since enjoyed. In the following year tramways were relaid in London, and the provincial towns soon followed its lead. The early tramways were horse operated, but many experiments in motive power were conducted with a view to increasing speed and carrying more passengers. In this connection steam locomotives and underground cables, which latter were adopted in Newcastle, Glasgow, and Edinburgh, may be mentioned. But the most pronounced improvement resulted from the adoption of electricity as a motive power.

An experimental electric line was constructed at the London Crystal Palace shortly after its opening, but the first electric tramway, properly so called, was not established until 1883. It was laid along the north coast of Ireland between Portrush and Bushmills and the Giant's Causeway, a distance of 8 miles. The line was constructed by the civil engineer Traill, and the electrical engineer Sir William Siemens. It is a 3-feet gauge line with some sharp corners and gradients. Electrical energy is generated by a waterfall at Bushmills, and is distributed along the track by a third rail, on which rubs a brush contact that is attached to the train, and transmits the electric energy to the electric motors on the train. A line of similar design was constructed in 1885, between Bessbrook and Newry, for the carriage of coal and flax from the wharves to the mills, the abundance of local water-power making an electric scheme very attractive. Electric tramways were constructed in Leeds in 1891, and from this date onwards other provincial towns adopted this system of locomotion. Progress in electric tramways was not as rapid, however, as might have been expected, owing largely to the restrictive character of existing tramways legislation, which dated from 1870, when the first Tramways Act was passed. The Act laid down "that the assent of the local and road authorities to a new line of tramways should be obtained; though where the assent of authorities in respect to two-thirds of the mileage was secured, the Board of Trade might dispense with that of any other objecting authority; that the frontagers were also to have a power of veto; that the original concession should be granted for a period of 21 years only; and that at the end of such period, or at the end of any

subsequent period of 7 years, the local authorities should have the option of acquiring the tramway at the 'then value' of the plant, without any allowance for compulsory purchase, goodwill, prospective profits, or other similar considerations."* This legislation was not very oppressive in relation to horse tramways, because the capital outlay required for these schemes was not excessive, and there was a reasonable chance of making average profits during the twenty-one years, and the "scrap value" of the stock, particularly of the horses, would not be very low. Very different considerations, however, applied in the case of electric tramways; capital outlay was heavy and was rendered necessary for the provision of power stations and substations and new car depôts; as also was the construction of overhead wires and a heavier type of track than was required for horse tramways; and the adoption of a car, also of more robust design, to withstand the greater wear and tear that takes place in electric as compared with horse tramways. Small wonder that under these circumstances development in electric tramways was slow. "There had been some expectation on the part of the tramway promoters that the general position would be improved by the Light Railways Act of 1896, many light railways being indistinguishable from tramways. Under this Act the assent of the local and road authorities is not required, and the frontagers' veto was done away with by it in the case of light railways; but authority to oppose was given to railway companies, and in practice the Light Railways Commissioners held that they ought not to authorize a tramway as a light railway unless it connected the area of one local authority with another. For these and other reasons the Act was not so beneficial with regard to tramways as had been anticipated."† In addition to the two systems of electric tramways, one involving the use of a third "live" rail, and the other of overhead wires, another system of outstanding importance is that in which the "live wire" is carried at the bottom of the conduit or underground channel usually situated between the rails, and contact is established through the medium of a "plough" which protrudes from under the car into the conduit. A later development of the electric tramway

* Pratt, *History of Inland Transport*, 455. † *Ibid.*, 457.

system is railless electric traction, in which electric power obtained from overhead wires is conveyed to cars, buses, and commercial lorries which run on the ordinary roads without rails, and consequently are not required to keep to closely defined paths. With this system not only is the capital outlay greatly reduced, but it is maintained that the running charges are lower than in the case of an electric tramway system, and that there is a further distinct advantage of quieter running. The first application in this country of railless traction was at the Hendon depôt of the Metropolitan Electrical Tramways. This was only of an experimental nature, the first commercial schemes being at Leeds and Bradford in 1911. The Leeds scheme involves the use of the ordinary rails within a radius of about 1 mile from the centre of the city, and the new system obtains within a further belt of 3 miles. The application of the system at Bradford is to unite two ordinary tramway systems.

Two of the earliest electric railway systems to be carried out in this country were the City and South London Railway and the overhead railway at Liverpool. The former was opened for traffic in December, 1890, and Mr. Greatheard acted as engineer, the contractors being Siemens Brothers and Mather and Platt. The line extended from "Monument" in the City to Stockwell, and on account of the heavy city traffic had necessarily to be placed underground. The method employed in constructing the tunnels was that of an iron conduit in segments, the earth being excavated, the water kept back by means of an iron shield and compressed air. The resulting iron tunnel, some 12 feet in diameter, is maintained perfectly watertight by being cemented on the exterior and concreted on the interior. These two tube tunnels, the "up" and "down" respectively, are placed side by side or one over the other as conditions dictate. The generating station, containing three dynamos, was constructed at Stockwell, and the electrical energy was distributed by means of a third and insulated rail placed between the main rails.

In connection with underground traction schemes two general considerations apply. Where tunnels are long steam engines are impracticable, as there is great difficulty in providing

adequate ventilation for removing the smoke, as the London tubes amply proved. In the second place, where stations occur at frequent intervals, electric traction has a distinct advantage over steam, as electric trains can attain maximum speed much quicker than steam locomotives, and hence electric traction as compared with steam gives for equal powers a shorter time interval between stations. The cost of operating electric trains is also reduced, since only one man, the driver, is required in the locomotive. This does not introduce a risk, should the driver be incapacitated, as by means of a "dead man's handle" control, the train is brought to a standstill when for any reason he removes his hand from the controlling lever.

The Liverpool Overhead Railway, the engineers of which were Sir Douglas Fox and Mr. Greatheard, was the first of its kind in Europe. Electricity was adopted as motive power, for since the railway ran so close to the docks, steam traction would have introduced a very heavy fire risk. It is 7 miles in length, and lies along the dock front adjoining the Mersey. The railway is supported by iron columns, and passes over canals and numerous streets. There are a great number of tilting bridges which only need to be raised to allow the larger ships to pass. An ingenious plan was adopted in the construction of the railway. The different sections of the bridge were constructed away from the site of the railway, and then run on trolleys to the site and lifted on to the appropriate columns. The line includes thirteen stations, and automatic signalling which is worked by the trains was adopted. It was opened in 1893. These early schemes conclusively demonstrated the practical and commercial success of electric traction, and they were quickly followed by other schemes. Forty years ago electric traction had barely progressed beyond the experimental stage, and the necessary apparatus of every kind had to be developed. To-day, however, apparatus exists in a perfected form to suit every class of demand, from the simple tramway motor operating a car of from 10 to 15 tons to the heaviest types of electric trains.

During the early years of the present century several steam lines, especially those of short length, were electrified. The

first line to be so transformed was the Mersey Railway, the change being made in May, 1903. As this line for the most part is underground, the steam trains were objectionable on account of the smoke nuisance in the tunnel. It is significant that during the period of steam traction this line was not financially successful, but since the change the line has been very prosperous. The success of the City and South London Railway made it possible to raise capital for similar projects, and gradually the extensive and ramified system of the Underground Electric Railways Company of London was evolved. Like the Mersey Railway the Metropolitan District Railway, which throughout its steam age was largely a financial failure, has, as a result of electrification and co-ordination with the other London "Underground" lines, been transformed into a dividend-paying concern. "Considered as a whole the results prove that where there is the potentiality of large traffic, electricity is the instrument which must be applied. During the steam days the most crowded part of the District Railway (the Inner Circle) carried a maximum of sixteen trains per hour. With electric traction that figure has been raised to forty trains per hour. It may be accepted as substantially proved that on suburban and interurban railways in populous districts electric traction is a means of increasing traffic and diminishing the proportion of working costs. Moreover these results have been achieved in conjunction with substantial reductions in fares and with marked improvements in the comfort of travelling."*

Electric traction has also been applied to suit special requirements, as, for instance, mountain railways having steep gradients. The first mountain railway constructed in the United Kingdom was 4¾ miles in length, running from Laxey to the summit of Snaefell with a gradient of 1 in 12 for practically the entire length. The line was opened for public use in 1896. Another special application is the transport of goods over short distances by means of electric trucks. Certain types of self-contained passenger and other electric automobiles have been developed which do not require wires. In the self-contained electric vehicle the power supplied to the motor is

* Whyte, *Electricity in Locomotion*, 105.

stored in an electric accumulator which needs recharging from time to time. This method was first adopted for public transport in Paris in 1882, and in this country in Birmingham in 1890, but its use for this purpose has not only been limited, but of doubtful success, mainly on account of the great weight of accumulators per unit of power, and the fact that they continually require recharging. At the present day this type of electric traction proves useful for small trolleys for the handling of goods over short distances in factories, wharves, etc., and for electric broughams.

III.—Electric Lighting and Power Generation and Distribution

The history of the early years of electrical development is almost entirely a history of electric lighting. The first electrical machines invented were used to supply electric power for illumination. Sir Humphrey Davy in 1801 first suggested the conversion of electrical energy into a luminant. He noticed that when an electric circuit was broken an electric spark was produced, and provided the broken ends were not taken too far apart, the arc continued. With a view to investigating this effect further Davy in 1808 requested a large voltaic battery from the managers of the Royal Institution of Great Britain, and he was provided with a large battery of 2,000 cells. The arc was made between the tips of two pieces of carbon, and an exceedingly brilliant light was obtained, but no practical application of this principle of lighting was made. Subsequent to the work of Faraday, Holmes, in 1857, had a permanent magnet machine constructed for the Trinity Board, and it was tested at Blackwall by Faraday. The results were good, and two larger machines were built with which, in 1858, carbon arc electric light was produced and was exhibited at sea for the first time at the South Foreland Lighthouse. These machines were afterwards removed to the Dungeness Lighthouse. Other machines of the same design and for the same purpose were later constructed by Holmes.

In 1863 H. Wilde of Manchester took out a patent for a machine in which electro-magnets were excited by means of a battery. Wilde constructed a large machine on this principle

to which he directed public attention in two papers read at the Royal Society in 1866: one, "On some new and paradoxical phenomena in electro-magnetic induction, and their relation to the principle of the conversion of physical force"; and the second, "On a new and powerful generator of dynamic electricity." The machine described consisted of a small magneto-electric machine, in which the magnets were permanent magnets, and the armature a Siemens armature, standing in a large magneto machine, in which the magnets were electro-magnets and excited by the current from the armature of the smaller machine. The current from the large armature was consequently very powerful. In 1867 Wilde exhibited a large machine at the conversazione of the Royal Society at Burlington House, lighting a bright electric light. In the same year two papers were read before the Royal Society: one by C. W. Siemens: "On the conversion of dynamical to electrical force without the aid of permanent magnetism"; and the second by Charles Wheatstone: "On the augmentation of the power of a magnet by the reaction thereon of currents induced by the magnet itself." These papers indicated new lines of development in dynamo construction, which led to the commercial dynamo. Dynamos of these types were built on a commercial scale by Gramme, Crompton, Siemens, and Ferranti; Mather and Platt constructed the Edison-Hopkinson design.

The state of the art of electric lighting may be judged from the following extract from the *Telegraphic Journal* of January 1, 1878: "The electric light has been conspicuously before us during the last year, and has made some decided advances both in the way of improvement and in its practical application. This activity has been almost exclusively confined to the Continent, where a great number of experimental trials have been made and works, warehouses, promenades, railway stations, ships and locomotives lighted by its means. In England it has been applied to transatlantic steamers and to ironclads as a means of defence, against the attack of torpedo boats made under cover of darkness. In June last the new 'electric candle' with the Kaolin wick of the Russian engineer, Jablokhkov, was publicly exhibited at the West India Docks and was considered to be a striking success." The Russian

invention referred to was made in 1876, and consisted of two rods of carbon placed side by side, but separated by insulating material, and an arc was struck at their tips. Its first adoption in this country, which also marks the beginning here of the electric lighting art, was on the Thames Embankment, in 1878, and it is of interest to note that Gramme dynamos were employed.

The earliest forms of arc lamps, worked by clockwork mechanism, were both complicated and expensive in operation, and unsuitable for street and public lighting. One great early difficulty was the lack of a proper source of supply of electric energy with which to operate the arcs, but the invention of the Gramme dynamo in 1870 solved this problem. Inventors were then immediately engaged in an endeavour to devise an electric light suited to domestic requirements, for the arc light was quite unsuited to lighting an average size room. Edison, in 1878, attacked the problem by electrically heating a carbon wire or filament, which he produced by burning a strip of paper in a small glass globe, and sealing it immediately after the air had been withdrawn. The English inventors Swan and his assistant Stearn about this time had also produced a successful electric lamp, which was exhibited in Newcastle on December 19, 1879, thus indicating the almost simultaneous reaching of the same result. The fact that up to this period electric lighting had only been successfully applied to outdoor illumination and to interiors through the medium of arc lights caused the belief to be established that electricity would never be a competitor with gas for ordinary domestic lighting. In fact, at a meeting of shareholders of the South Metropolitan Gas Company, held in 1878, the Chairman (then Mr. George Livesay) assured the shareholders that they had nothing to fear from electric lighting, since it had not been applied to domestic purposes. The news, however, of Edison's invention of the incandescent electric lamp had an immediate effect on the gas shares, and there was a great rush to sell out. Despite every effort to stem the tide, the South Metropolitan Gas Company's shares suffered a complete collapse.

One of the main difficulties in early electric lamps was the devising of a suitable carbon filament. The earliest attempts

by Sawyer and Mann were made by cutting the filaments from strips of carbon. Both Edison and Swan attacked the problem of carbonizing a fibre of organic matter, of such materials as paper, cotton, and silk, and Edison sent assistants all over the world to seek a suitable material. Of all that were tried, bamboo, split into fine filaments, proved to be the most successful, and until 1910 continued to be used to a great extent. Speaking of these early experiments, Edison observes: "It occurred to me that perhaps a filament of carbon could be made to stand in sealed glass vessels or bulbs which we were using, exhausted to a high vacuum. Separate lamps were made in this way, independent of the air pump, and in October, 1879, we made lamps of paper carbon, and with carbons of common sewing thread placed in a receiver or bulb made entirely of glass with the leading in wires sealed in by fusion. The whole thing was exhausted by the Spengel pump to nearly one-millionth of an atmosphere. The filaments of carbon, although naturally quite fragile owing to their length and small mass, have a smaller radiating surface and higher resistance than we dared hope. We had virtually reached the position and conditions where carbons were stable. In other words, the incandescent lamp as we still know it to-day (1904), in essentially all its particulars unchanged, had been born."* The next step in the development of the incandescent lamp was made by Swan, who devised a process of squirting through a small diamond die a nitro-cellulose material into a coagulating liquid, and afterwards carbonizing the filament so produced. Although Edison and Swan undertook separate research, they early recognized the benefits that would accrue from a joint exploitation of their patents. After having, in 1882, founded companies with a nominal capital of £1,000,000, they amalgamated in October of the following year, and formed the Edison and Swan United Electric Light Company, Ltd. This company produced the well-known Ediswan carbon incandescent electric lamp, which for twenty-five years continued to hold the field for indoor electric lighting, until the expiration of their patents, when many other makers entered the market.

Owing to the keen competition between electricity and gas

* Quoted by Luckiesh, *Artificial Light*, 129.

for indoor lighting, and to the fact that the carbon lamp had a very high electric current consumption, electrical engineers began to explore the properties of materials that might be substituted for carbon as a filament, and by 1906 the metals tantalum, tungsten, and osmium were shown to be suitable for this purpose. Filaments made of these metals brought for the first time the cost of electric lighting below that of gas. In 1914 another marked advance was made by the invention of the half-watt lamp, which uses tungsten as a filament, and replaces the exhausted globe by a gas-filled one; this lamp consumes only one-seventh or one-eighth of the current taken by the carbon filament lamp.

When, in 1882, the Ediswan lamp was put on the market, commercial men were quick to appreciate the possibilities of the new industry, and hastened to form companies for the purpose of supplying electricity for domestic lighting. A boom resulted, and wholly disproportionate sums of money were paid for right of supply. The passing of the Electric Lighting Act in 1882, which imposed stringent conditions upon suppliers of electricity, quite stamped out the boom, and even tended to repress desirable enterprise. This Act empowered the Board of Trade to grant Provisional Orders authorizing companies and Local Authorities to give a public supply of electricity in local districts. While the Local Authorities were granted powers in perpetuity, the companies were granted a maximum life of twenty-five years, at the end of which period the local authorities were empowered to purchase the schemes at "scrap-iron" value. Or, alternatively, the Board of Trade had power to grant licences to would-be suppliers of electricity for a period of seven years, after which the case would be reviewed and a further licence granted, subject to the Board's approval. Such legislation had a restrictive effect, and as experience of the operation of the Act was obtained, its repressive character became abundantly evident. During the first year of the Act 106 Provisional Orders were applied for, but only sixty-nine granted. Difficulty, however, was experienced in obtaining the necessary capital to finance these projects, and very few of the sixty-nine schemes were carried out. The result was that in the following year (1884) only four applications for "Pro-

visional Orders" were received. Consequent upon this state of affairs an amended Act was passed in 1888 and extended the period of tenure from twenty-five to forty-two years. This produced the desired effect; in 1889 seventeen Provisional Orders for electric lighting schemes were applied for, but in the following year the number rose to 161. In the London area private companies were in general the first to apply for powers, but in the provinces the local authorities were among the first to apply. A large number of towns, such as Birkenhead, Blackpool, Bolton, Burnley, Huddersfield, Hull, Lancaster, Leicester, Manchester, Nottingham, Oldham, Portsmouth, Salford, Stafford, Walsall, and Yarmouth, received their electric lighting powers in 1890 or 1891. During the closing years of the nineteenth and the opening years of the twentieth centuries, applications for Provisional Orders were made involving far larger and more ambitious schemes than had hitherto been proposed. In fact, permission was sought by authorities to build stations outside the areas authorized by the Lighting Acts. The Government appointed a Joint Committee of the Lords and Commons to consider the whole problem, and the following paragraph from their report indicates their main decision to grant recognition to the principle of power supply and distribution on a large scale: "Where sufficient public advantage is shown powers may be given for the supply of electrical energy over an area including districts of numerous local authorities and involving plant of exceptional dimensions and high voltage." The first scheme to be approved under this ruling was the South Wales Electrical Power Distribution Company, which was authorized in 1900 to supply power to practically the whole of the industrial area of South Wales. Such a scheme obviated the necessity for individual works installing their own electric generating plant, a course they would not desire to take, since the supply of power "in bulk" from a central power station is infinitely cheaper per unit than the cost of generation in small quantities at a number of small stations.

The beginning of the present century saw the first real progress towards the generation and distribution of electricity for supply purposes on anything like a large scale, particularly

the years preceding the war, from 1900 to 1914. It was during this period that the Government passed nearly all the Acts relating to the supply and distribution of electricity under which the twenty-nine power companies in this country operate. From 1910 moderate sized steam turbines began to be more generally adopted as prime movers for the generation of electricity, and due to the proved increase in economy and reliability the demand for electric energy for power and other purposes increased considerably, and but for the war there is reason to believe great developments in electricity supply and distribution would have taken place. With the cessation of the war the electricity undertakings prepared to go ahead, but progress was suddenly arrested by an announcement that the Government intended enacting legislation in order to control development in electricity supply. This legislation ultimately took the form of the Electricity (Supply) Act, 1919. By this Act a new body, called the Electricity Commissioners, was appointed, in which was vested power for regulating, encouraging, and in a large measure controlling, the generation and distribution of electricity in the United Kingdom under the general direction of the Minister of Transport, who has power to spend £20,000,000 for the erection of emergency generating stations and main transmission lines. Since the Act came into force the Electricity Commissioners have been holding inquiries with a view to improving the existing organization for the supply of electricity.

The Age of Electricity, no less than the Age of Steam, is making its mark on the whole industrial and social organization of the country. The Age of Steam, while conferring distinct benefits on mankind by conserving human effort, nevertheless produced certain undesirable conditions, particularly the crowding together in industrial centres of large aggregations of population. The one peculiar characteristic of steam is that it must be used on the coalfields where it is most cheaply generated, since every foot of steam piping means great loss of power. As the Age of Steam advanced, the whole of the coalfields of England became covered with industrial towns with dense populations. Electricity, however, does not impose

this condition. Exceedingly small losses take place in the case of the distribution of electrical energy over long distances, and hence large electrical generating stations can be erected on the coalfields, where an abundant supply of cheap coal is available, and electrical energy so generated can be transmitted over a distance of many miles without appreciable loss. Factories can be distributed over a very wide area, and with cheap electrical transport facilities the industrial population can similarly spread itself over a wide residential area. In these two ways the crowding of population in industrial towns can be avoided. We have excellent examples of this in America, where, for instance, electrical power generated at Niagara is transmitted a distance of twenty-five miles to the town of Buffalo. Already in this country we see the gradual migration of industries away from the town into the country. The Metropolitan-Vickers works are located several miles from the heart of the city of Manchester. The General Electric Company's works at Witton near Birmingham, Crompton works at Chelmsford, the British Thomson-Houston works at Rugby, are other examples, and there are besides a host of other industrial concerns, both engineering and non-engineering, too numerous to mention. There is no need for the workers employed in these large corporations to be huddled together in houses immediately adjoining the works, as with the development of electric transport cheap and rapid travelling facilities are available which enable workers to reside a distance from the works.

Electricity has been instrumental in bringing much closer together all parts of the world. We have noted earlier in this chapter that as the result of the development of radio-telegraphy the most distant parts of the world are divided in point of time by not more than one-fifth of a second. Any important event in any part of the world can almost immediately be made world-wide knowledge. This swift communication has also a very important economic effect, especially in facilitating international trade. The market quotations in New York, for example, are known half an hour later in London, and this information greatly facilitates business transactions. In the home the development of electricity has conferred distinct

benefits mainly by reducing the amount of manual work to be done, for it produces no smoke and much less dust. The modern home is equipped with electric light; electric cookers, sewing machines, fires and radiators, irons, boilers, and cleaners, lighten the lot of the housewife; electric fans, bells and telephones add to the domestic amenities. And, finally, electricity has contributed to the alleviation of human suffering, and facilitated surgical progress. X rays have been applied to the rapid detection of fractured bones, to the locating of foreign bodies and certain types of diseases. Small electric motors are also used for driving surgical appliances, and expedite the work of the dentist in many of his operations. The electric cautery, whereby a delicate wire is electrically heated to white-heat and applied to the spot to be burnt, quickens operations requiring this treatment. Electric massage has of recent years become an important branch of medical treatment.

CHAPTER XI

ORGANIZATION OF PERSONNEL IN THE ENGINEERING INDUSTRY

"OUR fields are cultivated with a skill unknown elsewhere, with a skill which has extracted rich harvests from moors and morasses. Our houses are filled with conveniences which the kings of former times might have envied. Our bridges, our canals, our roads, our modes of communication, fill every stranger with wonder. Nowhere are manufactures carried to such perfection. Nowhere does man exercise such a dominion over matter."* In these words Macaulay, in the course of a debate on the Reform Bill, contrasted the high standard of English life with the low standard of its Government. Certainly the epoch-making changes to which Macaulay referred had been witnessed by many of his listeners in the last Unreformed Parliament. They had seen "the dazzling birth ot modern England." Roads, bridges, canals and aqueducts had been built; the first steamer had been launched on the Clyde; railway construction had commenced, and a host of inventors had succeeded in making England the workshop of the world. When George III. ascended the throne woollen goods were the most important manufacture of England, whereas cotton exports were negligible; at the time of Macaulay's speech "her cotton exports were worth some 18 millions, her total exports had risen from 14 to over 60 millions, and her imports from 9 to 40 millions."†

This outburst of manufacture was as sudden as if was extensive. Prior to the inventions of Arkwright, Watt, and Boulton, England's industries were carried on mainly under the domestic system, but their mechanical inventions completed the change to the factory system. Attempts were made to educate the workers to appreciate the ultimate advantages of machinery.

* Quoted by Hammond, *The Town Labourer*, I.
† Cunningham, *Growth of English Industry and Commerce.*

In 1831 the Society for the Diffusion of Useful Knowledge published a book entitled *The Results of Machinery* which described in glowing terms the beneficial results accruing to the workpeople from the introduction of machinery. William Cobbett explained in the *Journeymen and Labourers of England, Wales, Scotland, and Ireland,* the true significance of the introduction of machinery, and showed that, although in some directions there would be an immediate adverse effect, yet in the long run it was to the workers' own interest that the application of machinery should extend. In 1831 Lord Brougham obtained permission from Cobbett to republish the address, so important an influence was it supposed to possess. "Machinery enables the poor to obtain at a cheap rate many comforts which they could not otherwise possess. The fallacy often prevails that machinery dispenses with hand labour, but machinery must first of all be made with hands. Moreover, machinery does not diminish the capital of a country, but it increases it, and this capital is still employed in the payment of wages. It is, however, true that there is often a shifting of the parties to whom the wages are paid. The remedy for this is for the working man to learn the faculty of turning his hand to any new employment when he finds it necessary to do so." The ultimate effect of the increase in the use of machinery has undoubtedly been to improve the lot, as a whole, of the worker. The actual unemployment and hardship incurred by the replacement of hand processes by machinery is not nearly so widespread as is generally supposed. The process of displacement is invariably a slow one, and the handworkers displaced are usually absorbed in the readjustment of the industry in other branches of work, frequently in the same factory. An immediate effect of the extension of machine processes is to reduce manufacturing costs, bringing within the purchasing power of large masses of the community conveniences and amenities which without machine manufacture would be sold at prohibitive prices. Hours of labour have been shortened, and actual physical fatigue is invariably much less to-day than in the days of hand labour. The compensation for the increase in monotony of work, such as must always be the rule with machine minders, lies in the shorter hours of labour, which

afford a greater leisure for cultivating other interests. With the spread of education it is easy for workers to take a wider interest in life and affairs than hitherto, and the extent to which they avail themselves of their opportunities is largely a matter of individual desire.

The new access of wealth provided by the mechanical inventions of the industrial revolution contributed largely to establishing Britain's premier position among the nations of the world. It enabled this country to break the power of Napoleon. Lecky,* writing of the effect of the inventions of Watt and his fellows, observes: "Gradually during the last twenty years of the century this new engine came into use as the motive power in manufacture, performing with enormously increased strength and efficiency what had formerly been done by human muscles, by animals, by wind and by water. No other invention since the discovery of printing has affected so widely, so variously and so powerfully the interests of mankind . . . the triumphant issue of the Great French War was largely, if not mainly, due to the cotton mill and the steam engine. England might well place the statues of Watt and Arkwright by the side of Wellington and Nelson, for had it not been for the wealth they created she could never have supported an expenditure which during the last ten years of the war averaged more than £84,000,000 a year and rose in 1814 to £106,000,000, nor could she have endured without bankruptcy a national debt which had arisen in 1816 to £885,000,000." Though Lecky has nothing but admiration for the great resources of wealth that Watt's inventions had heaped up for the nation, his words contained, as it were, a prophecy only too well fulfilled in our own day. Wealth and invention have vastly increased the area and devastations of war. The Great War has clearly demonstrated the unlimited destructive powers that scientific research and engineering development have put into our hands. Unless they are properly controlled by a quickened international moral sense they constitute an ever-present danger to human institutions and achievement. This is an aspect of engineering advancement which is too frequently overlooked.

* Lecky, *History of the Eighteenth Century*, VI. 217.

Once the evil consequences of factory conditions upon human life were appreciated, definite steps were taken to secure their improvement. The year 1802 may be regarded as a turning-point, and viewing industrial progress in the broadest way it might be said that "prior to that date legislation was directed towards the prevention of idleness, whereas after that date all legislation affecting industry was invariably designed to prevent overwork." The Health and Morals of Apprentices Bill of 1802 became really the first of a long series of Factory Acts, each one of which in turn afforded a greater measure of State protection to the industrial worker combined with a distinct effort to render his working conditions more palatable. Beyond State regulation of factory conditions and hours of labour there is to-day provision for old age, unemployment, sickness and accidents.

The development of the engineering industry has resulted in a progressive disintegration of handicraft into a large number of specialized operations. An account of the qualifications of a millwright of a century ago is given by Sir William Fairbairn,* and shows the comprehensive character of his work, necessitating a wide and very general training. "The millwright of the last century was an itinerant engineer and mechanic of high reputation. He could handle the axe, the hammer and the plane with equal skill and precision; he could turn, bore or forge with the ease and dispatch of one brought up to these trades, and he could set out, and cut in, furrows of a millstone with an accuracy equal or superior to that of a miller himself. . . . Generally he was a fair arithmetician, knew something of geometry, levelling and mensuration, and in some cases possessed a very competent knowledge of practical mathematics. He could calculate the velocities, strength and power of machines; could draw in plan and section, and could construct buildings, conduits or water-courses, in all the forms and under all the conditions required in his professional capacity; he could build bridges, cut canals, and perform a variety of work now done by civil engineers." And again: "A century ago the small skilled class of millwrights executed every kind of engineering operation, from making the wooden

* Fairbairn, *A Treatise on Mills and Millwork* (1861), Preface.

patterns to erecting in the mill the machines which had been constructed by their own hands. The enormous expansion of the engineering industry has long since brought about a division of labour, and the mechanics in a great engineering establishment to-day are divided into numerous distinct classes of workers who are rarely able to do each other's work. The pattern makers working in wood have been sharply marked off from the boiler makers and the iron founders . . . each generation sees a great development in the use of machines to make machines, so that a modern engineering shop, in addition to the time-honoured lathe, includes a bewildering variety of drilling, shaping, boring, planing, slotting, milling and other machines attended by wholly new classes of machine minders and tool makers. Finally we have such new kinds of work with new classes of specialists as are involved in the innumerable applications of iron and steel in modern civilization, such as iron ships and bridges, ordnance and armoured plating, hydraulic apparatus and electric lighting, sewing machines and bicycles."* Manual workers in the engineering industry can be regarded as comprising two broad types: one, a machine minder who simply feeds a machine with raw material, operates the mechanism by some simple control such as hand-wheel, lever, or press button, and then withdraws the resulting product. The second type comprises workmen who possess some definite craft skill and who have acquired by training and experience a fairly wide knowledge of operations and processes falling within the scope of their trade—a class which includes such skilled workers as moulders and pattern-makers, turners, fitters, and armature winders.

The proficiency of the old millwright could be acquired only through the medium of a long apprenticeship course, but with changes in the engineering industry the character of apprenticeship has also altered. Apprenticeship was made legally compulsory by the Statute of Apprentices of 1563, although at that time the smith was regarded as practically the sole representative of the engineering industry. According to this Statute an apprenticeship of seven years was necessary, and there is no doubt that the Legislatures of that period were

* Webb, *Industrial Democracy*, 108.

prompted by a desire to maintain a high standard of skill among the country's workmen. Although the Statute of Apprentices was repealed in 1814, we still find that during the early years of the nineteenth century local trade union clubs of smiths and millwrights refused to accept as members those who were unable to produce their indentures. Sir William Fairbairn relates how, when in 1811 he obtained a situation as a millwright at Rennie's, the foreman told him that he could not start until he had been accepted by the trade union. Failing to prove duly attested indentures he was refused admission to work, and driven to tramp away from London and seek a situation in a non-union district.* Gradually, during the past century, apprenticeship indentures in the engineering industry have fallen into disuse, and the majority of those who enter the engineering trades as apprentices are not bound under any form of agreement. Too frequently they acquire their practical experience in a haphazard manner by transfer from one type of work to another within a given works, or by movement between different works. The relaxation of trade union requirements has also influenced the decline of apprenticeship, for to-day a youth whose training has in effect been very inadequate can, nevertheless, secure admission to a trade union. It may be argued that the evolution of engineering processes is such as not to require in the future a workman skilled in many operations, but only an operator familiar with one or two specialized processes. Such a line of argument, however, takes a very narrow interpretation of apprenticeship, and ignores the fact that the acquisition of manipulative skill, together with an intimate knowledge of machine processes, is, though an integral part, still only a part of the complete training of a trade apprentice. In some of the larger engineering works in the country where a broader meaning is attached to apprenticeship, not only are apprentice instructors appointed for the particular purpose of ensuring that apprentices receive proper and adequate training in their trade, but classroom teaching is also given in the economics of industry, the privileges and duties of industrial citizenship, and the general significance of engineering, to enable the

* Pole, *Life of Sir William Fairbairn*, 88, *et seq.*

embryo workman to relate his own individuality to the whole.

It is unnecessary to go so far back as the craft gild stage of industrial organization for evidence that, in former times, the apprentice was in very intimate contact with the journeyman, and that it was this mutual association which enabled the apprentice to reproduce so faithfully the skill of his master and to advance in the practice of his trade. Both masters and journeymen evinced keen interest in the training of apprentices, and prided themselves on being able to produce in an apprentice attaining the age of twenty-one years trade skill of no mean order.* This same condition applied during the industrial revolution, but in recent times has practically ceased to exist. In many of our larger works to-day apprentices are engaged in work of a totally separate character from that on which journeymen are employed, and frequently undertake this work in a different part of the shop. The apprentices report direct to a charge-hand or foreman, who consequently accepts moral responsibility for apprentice training. In short, very little opportunity exists to-day for that intimate contact between workman and apprentice which years ago constituted the mainspring of apprentice training, and the solution for modern workshop conditions lies in apprentice instructors and classroom teaching.

The history of vocational training by educational bodies goes back over a hundred years. In the early days of the industry the pioneers of engineering development acquired the limited available technical knowledge through hard study of the few books on engineering science that were then written. The development of the industry has been accompanied—indeed, brought about—by scientific research and the practical application of technical principles, and as discoveries and advances were recorded in books and journals an increased technical literature became available for the engineering student. To meet the needs of working men, especially those engaged in the

* Lipson, in *The History of English Woollen and Worsted Industries*, cites the case of a West Riding master clothier, who stated in 1790: "Yes; we think it a scandal when an apprentice is loose if he is not fit for his business; we take pride in their being fit for their business, and we teach them all they will take" (page 75).

engineering and allied trades, special lecture courses were delivered in Anderson's College, Glasgow, as early as 1823. This experiment resulted in the establishment of Mechanics' Institutes in many industrial towns. A Department of Science and Art was set up by the Government in 1853 and, under the auspices of this Department, which was later transferred to the Board of Education, extensive facilities have been provided for the technical education of boys and young men engaged in industry, and the engineering industry specially has benefited. To-day, through the medium of evening classes, youths engaged in whole-time engineering employment have the opportunity of obtaining sound technical knowledge such as will enable them to undertake technical, as distinct from manual, employment. The inference that technical knowledge and its application is the main distinguishing characteristic between the professional engineer and the engineer-workman, is correct. The young man, however, who desires to become a professional engineer does not relegate this important part of training to evening periods, but graduates from a University having a faculty in engineering. The University course, extending usually over three or four years, and followed by at least two years' practical training, preferably in a manufacturing works, is regarded in general as the minimum preparation for the higher branches of engineering employment.

The increasing subdivision of engineering processes has already been noted. During recent years an effort has been made on the part of many industrialists to reduce manufacturing costs by refining still further the subdivision of labour. A system of factory management embodying this principle was introduced into the United States some twenty-five years ago by Dr. F. W. Taylor, who set forth his ideas in a paper entitled "A Piece Rate System: being a step towards partial solution of the labour problem." His system, which has since become known as "Scientific Management," involves a splitting up of any job into a large number of component parts and predetermining a time allowance for each part of the job with an appropriate piece-work price. It also presupposes the determination of the best way of doing a job, and the elimination of all unnecessary waste of time, effort, and material, and

the consequent reduction of fatigue on the part of the worker to a minimum. Three special problems arise as an integral part of scientific management, known respectively as motion study, time study, and fatigue study. Motion study usually results in increased output, since unnecessary operations and wasteful movements are eliminated, and while in a given time a greater amount of work can be done, it frequently involves less effort. "To suppose that skill cannot be communicated or assisted by instruction is to place a serious limitation on industrial development; for one of the most striking developments in modern management is the application of the highest intelligence to the guidance of workers of the lowest intellect, being no loss of directive power to the order passing from the executive through a number of grades of workers before it reaches the individual effect." Motion study and time study are really two aspects of a common problem: the former primarily refers to the operative and the latter to the machine operator. The function of time study is to analyze in close detail the time taken to perform each component operation of a job and to undertake studies on such operations as the setting up of machines, handling of tools, and the placing of materials. Time study refers equally to hand and machine work, and gives a minimum time in which a job can be executed under the best conditions. Taylor, in propounding his system of scientific management, directed attention to the problem of industrial fatigue. He urged the importance of rest periods during which workers fatigued by continuous effort might recuperate. "Fatigue is caused by the accumulation in the blood of toxic products arising from nervous and muscular activity, and the continuance of work without intermittent rest periods results in an accumulative clogging of the tissues to such a degree as ultimately to cause complete stoppage of the human mechanism. In all forms of human activity it is essential, therefore, to provide a suitable alternation of working and rest periods, so that during the rest period the poisonous products arising in the body as a result of active physiological processes may be removed. Physiological research shows that longer periods of rest are necessary after night and week-end work than are required by weekday work only. This forms

the argument for avoidance of overtime and Sunday work and for works holidays."* Numerous examples are available, many from the engineering industry, of increased production as a result of the proper alternation of work and rest periods.†

Arising largely out of the application of scientific management new methods of wage payment have from time to time been introduced into sections of the engineering industry. The oldest and simplest method of wage payment is the day-work system, whereby a certain weekly wage is paid for a pre-determined number of hours spent at work. Any absence from work results in a proportional reduction of wage. It is clear that this system of wage payment admits of a great range in both quality and quantity of work done by individual employees. At the one end of the scale a worker's product may become so poor in quality, or so small in amount, as to call for dismissal. At the other end is a workman who, by reason of ability and perseverance, produces a large amount of first-class work that earns promotion. But it is clear that between these two extremes lies a great range of personal performance. "In order to provide an incentive to effort on the part of the worker and to secure his interest in work done, the piecework system has been introduced. Numerous forms of this system have been devised, some of which are quite impracticable and can only be regarded as paper schemes, whereas others have met with varying degrees of success and have within limits attained the objects for which they were designed. Chief among piece-work systems, because the simplest, is the straight piecework system, where a definite price is set per piece and the worker's wages are the product of the price per piece and the number of pieces completed in a working week. Such a system as this immediately gives the worker a very direct interest in the number of pieces or operations which he completes. It has been said that the surest and shortest way to a worker's interest is through his pocket, and this is the main reason for the success

* Fleming and Brocklehurst, *Industrial Administration*, 114.

† One such example may be cited in which girls engaged on repetition work in a munition factory were allowed three rest periods per day, each of forty-five minutes, one being the mid-day lunch period. When these times were rearranged so as to make eighty minutes' work and twenty minutes' rest throughout the day, the output went up 60 per cent. and an arrangement of additional help avoided idle machinery.

of the piecework system of wage payment. It is usual under this system to guarantee a certain minimum wage, purely on a time basis, irrespective of the amount of work performed, in which case supposing a full week's attendance to have been registered, the difference between the total piecework earnings and the guaranteed minimum wage rate of a worker is known as piecework bonus. Under these conditions occasions may arise when the worker fails to earn his minimum wage on a piecework basis, in which case he goes into debt from which he is freed by deductions from subsequent bonuses. It is usual also to make allowance for a certain training period in the case of new workers, the duration of this period varying according to the character of the work to be done. An appropriate wage is paid the learner during this probation period, at the completion of which he is put on a piecework basis and from that point onwards failure to earn piecework bonus is regarded as a sign of inefficiency, which if continued, probably results in the dismissal of the worker. Among large sections of organized labour there is very definite opposition to this system of wage payment, and their hostility is not without a measure of just cause. Too frequently in time past have employers cut piecework prices when through sheer industry workers have earned very high wages, and such action on the part of employers has naturally been met with the policy of 'ca'canny' or 'going-slow' on the part of workers, especially when certain prices have been set too high and honest work would have resulted in extremely high wages. But in general employers are no longer guilty of cutting piecework prices; in fact it can be affirmed that only on condition of a process being changed is a piecework price altered. On the other hand there are many instances of employers having raised low rates in order to permit workers to earn satisfactory wages. It is clear from the above analysis of the straight piecework system that every saving of time on the part of a worker by increasing his output is turned in full to the worker's account. Each product completed or each operation performed costs the employer the same in wages, and while not ignoring the saving which is effected on account of reduced overhead expense per product with an increased number of completed products, the fact

remains that increased efficiency of the workers, whether brought about by special effort on their part, or by provision of better working facilities, does not result in a direct gain to the employer. The premium bonus system of wage payment aims at sharing the value of increased output between the worker and the employer. The most generally known scheme of premium bonus in this country is the Rowan Scheme, introduced by Mr. James Rowan, of David Rowan and Sons, Glasgow. It is a somewhat complicated system under which, if a workman reduces the time he takes to do a job by a certain percentage, he is given an equal percentage of increase in his hourly rate. Thus, if a workman whose rate is 2s. per hour finishes an 8-hour job in 6 hours—thereby saving 25 per cent. of the time—he receives the hourly rate for 6 hours, that is, 12s.+25 per cent., or 3s., thus making a total for the job of 15s., and the time rate, therefore, 2s. 6d. per hour, or 20s. per 8-hour day. Premium bonus systems in this country have been very limited in their application, largely because of their complicated character and of the opposition of workmen to the systems—opposition largely brought about because of the difficulty they experience in calculating what their week's earnings should be in any given case. It may be affirmed that no system of wage payment is successful if the man who is being paid by it does not clearly understand the method by which his wage is calculated. Premium bonus systems are, therefore, more applicable to workers of high intelligence than to those of lower grades."*

Trade unionism has played an important part in the develop-

* Fleming and Brocklehurst, *op. cit.*, 96 *et seq.* In America the Halsey scheme is the best known of the premium bonus systems. The essence of this system is that a standard time is agreed upon in which a given job is to be done, and the workman receives an agreed percentage of the wages of any portion of this time he may save, in addition to the regular time rate for the period taken. Thus, if the time limit set on a job is twenty hours and the workman by finishing the job in sixteen hours saves four hours, if the agreed percentage of the time saved is 50 per cent., and his hourly wage on a time basis is 2s. per hour, then his wages for the period taken by the job will be; sixteen hours at 2s. per hour+50 per cent. of the four hours saved=32s.+50 per cent. of 8s.=32s.+4s.=36s.

In contrasting the Halsey and the Rowan systems, it will be seen that under the Rowan system savings of time result in smaller premiums to the worker, and this tends to protect firms which are unable to set accurate premium times.

ment of the engineering industry, and has exercised a distinct influence on the character of the management of individual works. "The origin of trade unionism in the engineering trades is obscure."* The original millwrights who possessed strong trade societies were gradually replaced on the introduction of the steam engine by workmen specialized in particular branches of the trade, who before long formed themselves into a number of rival trade societies. Early in the nineteenth century there were evidences of a tendency to greater unity of action between these bodies which first showed itself in London and Lancashire. In 1836 a number of these societies declared a strike which lasted eight months, but which ended successfully for the unions in so far as they secured a reduction of the working week to sixty hours, and extra payment for overtime. A further reduction of hours was secured in 1844. These early successes showed the value of greater co-ordination, and William Newton, an engineering foreman, who later lost his position through his interest in trade matters, became the leader of a movement for national amalgamation of the rival societies. Newton belonged to the Journeymen Steam-Engine and Machine Makers' Society, and his society took the lead in the move towards amalgamation; he was greatly helped by William Allen, the general secretary of the society. They published in Manchester a weekly journal, the *Trades Advocate and Herald of Progress*, for the purpose of advocating and promoting the cause of amalgamation. The scheme was finally accepted at a delegate meeting held in Birmingham in September, 1850, but it was not until January, 1851, that the Provisional Committee that had been earlier formed took office as the Executive Committee of the "Amalgamated Society of Engineers," the name of the new body. Even then one society, the Steam-Engine Makers' Society, took exception to amalgamation, and remained out until the end of 1919, when with other societies it joined with the Amalgamated Society of Engineers in the formation of the Amalgamated Engineering Union.

The first aggressive act of the new Amalgamated Society of Engineers was a fight against overtime, which resulted in a

* Webb, *History of Trade Unionism* (ed. 1920), 204.

lock-out by the employers as from January 1, 1852, the employers having first combeind to resist the society's claims by forming in December, 1851, the Central Association of Employers of Operative Engineers. The men's funds ran low, and the employers opened their shops in February to anyone who would not only relinquish the society's demands, but sign a " document " indicating that he had left the society. During April economic pressure forced the men to return on the employers' terms, and in the majority of cases the signing of the " document " was insisted upon, although it was an open secret that the men had not left and had no intention of leaving the society. The lock-out seems only to have stimulated the progress of the society, for in the following ten years the membership was doubled, and by 1861 it had collected a credit balance of £73,398, at that time an unprecedented amount. The next great struggle and achievement in its history was the effort commenced in 1871 to secure a nine-hour working day. The Sunderland branch took the remainder of the society by surprise by coming out on strike on April 1, 1871, in demand for a nine-hour day. After four weeks' strike the local employers conceded the men's demands. It was natural that the movement should spread over the country, and in order to wage the fight unionists and non-unionists were formed into a " Nine-Hours League," led by John Burnett, who later became general secretary of the society. " The five months' strike which led up to a signal victory for the men was in more than one respect a notable event in trade union annals. The success with which several thousands of unorganized workmen, unprovided with any accumulated funds, were marshalled and disciplined, and the ability displayed in the whole management of the dispute, made the name of their leader celebrated throughout the whole world of labour. The tactical skill and literary force with which the men's case was presented achieved the unprecedented result of securing for their demands the support of *The Times* and the *Spectator*."* Finally the employers conceded the men's demands, and the fifty-four hour week became recognized throughout the engineering trades.

* Webb, *History of Trade Unionism*, 315.

Improvements in trade union organization were met by similar developments on the other side, and led to the formation in 1873 of the National Federation of Associated Employers of Labour, which was an amalgamation of two previous national organizations, the General Association of Master Engineers, Shipbuilders, Iron and Brass Founders, and the National Association of Factory Occupiers. The Federation stated that it had been formed " in consequence of the extraordinary development, oppressive action, far-reaching but openly avowed designs, and elaborate organization of trade unions. Its object is, by a defensive organization of the employers of labour, to resist these designs so far as they are hostile to the interests of the employers, the freedom of the non-unionist operatives and the well-being of the community." The twenty-five years that followed the success of the " Nine-Hours League " in 1871 were marked by a great amount of internecine war among the rival trade unions. New demands were continually being made by the unions, but " among the causes of disputes those not concerned with wages were increasing in number and importance. They included hours of work; the employment of a particular class of persons; disputes between classes of workmen; working arrangements, rules and discipline; trade unionism and sympathetic strikes. In short, the question of management was raised, and it became the central issue, though obscured by the demand for an eight-hour day and local wage questions."* In the early part of 1897 numerous small strikes occurred in various parts of the country, notably on piecework at Oldham and on the eight-hour day in London. The latter trouble spread throughout the country, and was met by general lock-out notices, which began in July and eventually affected 702 firms and involved 47,500 men. In describing the dispute the official Board of Trade account states: " Though the immediate cause of the general dispute was the demand for an eight-hour day in London, the real questions at issue between the parties had become of a much more far-reaching kind, and now involved the question of workshop control and the limits of trade union interference." A six months' stoppage resulted, in which the

* Shadwell, *The Engineering Industry*, 21.

funds of the A.S.E. were depleted, and ended in a victory for the employers. The agreement was signed on January 28, 1898, on behalf of the Employers' Federation and the A.S.E. with seven other unions.

The national agreement of 1898 was revised in 1901 and again in 1907, on each occasion being made slightly more favourable to the unions. The operation of the amended agreements proved unsatisfactory, however, and prior to the war disputes continually arose on the question of "manning of machines," the employers claiming that they had the right within the legitimate exercise of their "managerial functions" to set any man to work any machine. The matter was brought to a head at the end of 1913, when the A.S.E. gave notice to the employers to terminate the agreement of 1907, and until June, 1922, there was no agreement in force covering the general relations between engineering employers and the trade unions, and defining the powers and functions of each. In order, however, that there might be some agreed procedure for dealing with matters as they arose for consideration between the engineering employers and trade unions, both were parties in April, 1914, to the York Memorandum or Provisions for Avoiding Disputes. The Memorandum laid down that an attempt must first be made to settle a dispute in the works where it arises; failing this it should become the subject of a local conference between the Employers' Association and the union or unions concerned; and failing settlement in this manner should be referred to a Central Conference* between the Engineering Employers' Federation and the union or unions affected. No stoppage of work was to take place until this procedure had been followed.

The outbreak of war in August, 1914, created an urgent need for the rapid manufacture of munitions; and that such work should not be retarded by trade union restrictions or disputes involving stoppages of work, the Government called together the trade union leaders and entered with them into what is known as the Treasury Agreement, 1915, which was subsequently incorporated in the Munitions of War Act, 1915. Under the Treasury Agreement the unions renounced some of

* Central Conferences are held at York.

the main features of trade unionism, such as shop rules and regulations and the right to strike, and were promised by the Government their complete restoration when the war should end. In this connection one clause of the Munitions Act, 1915, read: "Any departure during the War from the practice and ruling in the workshops, shipyards and other industries prior to the War shall be only for the period of the War and must be absolutely and completely reinstated when the War is over." The speeding up of engineering production which resulted, together with the introduction of women and unskilled labour into munition factories and engineering works—known as "dilution of labour"—awakened suspicion and discontent among a large section of the "rank and file" of the engineering trade unionists, and they soon developed a new channel through which to express their hostility to the Munitions of War Act. "Shop stewards" had been in existence and had usefully functioned long before the war, but after 1915 they assumed a new function and importance. Normally shop stewards "are persons elected by the men of each craft in each department of an engineering shop to act individually, or through a 'convener' of all the shop stewards of the particular craft as the connnecting link between the men of that craft in the works, and the district delegate or district committee of the craft trade union."* With the growing discontent among large sections of the workers in the engineering industry shop stewards and shop stewards' committees gradually usurped the functions of trade unions and, acting directly on behalf of the "rank and file," flouted the orthodox trade union leaders who had been parties to the Treasury Agreement. The two most notable outbreaks in the shop steward movement were on the Clyde in March, 1916, and at Coventry in November, 1917. The Coventry strike resulted in the recognition of the shop steward movement by employers and the trade unions, after which they were given a place in the organization of the latter.

Prior to the Coventry outbreak the Government had made an attempt to discover a new basis for dealing with disputes in industry, and had appointed a Government Committee, since

* Macassey, *Labour Policy*, 79.

known as the Whitley Committee, from the name of its chairman, with terms of reference to make and consider suggestions for securing a permanent improvement in the relations between employers and workmen, and to recommend means for securing that industrial conditions affecting the relations between employers and workmen shall be systematically reviewed by those concerned, with a view to improving conditions in the future. The Whitley Report, issued in 1917, recommended the establishment for each industry of a triple organization—in the workshops, the districts, and nationally—to be known respectively as Works Committees, District Councils, and Industrial Councils. The organization at each stage was recommended to be composed of representatives, in equal number, of workpeople and employers. In the engineering industry the equivalent of District Councils and a Joint Industrial Council exists in Local and Central Conferences, described above.* Numerous Works Committees have been formed in the engineering industry, mainly in large works, and have, in general, accomplished useful work. Subjects for discussion extend over a wide range, including, for example, conditions of employment, better utilization of experience of workpeople, the provision of educational facilities, and improvements in processes, machinery, and organization. Most important among the results of Works Committees is the creation of an atmosphere suitable for reasonable discussion between employers and workpeople.

At the end of the war a notable step was taken in the engineering industry, when by mutual agreement a forty-seven-hour week was established. The change came into effect on January 1, 1919, and a six or seven hours a week reduction was obtained without any reduction of pay rates, the unions undertaking to maintain output and to enter into provisions for avoiding disputes. Numerous abortive attempts were made by certain sections of the trade unions to secure further reductions in the length of the working week. The restoration of a number of war practices in the engineering industry which had been restricted by the Munitions of War Act, 1915 was carried out quietly but effectively. As a whole, industry

* *Supra*, 288.

was greatly disturbed, and the period immediately following the war was marked by disputes which exceeded in number and magnitude those of any year since 1913. Nevertheless, the engineering industry displayed unexpected steadiness. " Very little public attention has been drawn to the restoration of trade union practices precisely because it was accomplished so quietly. The objectors to suspension, who had predicted infinite trouble through assumed breaches of faith, found their predictions falsified and dropped the subject, since no controversial capital could be made out of it. The pledges given by the Government and the employers were so well kept that out of 30,000 records of changes supplied to the Government, in only twenty-two cases were proceedings taken against firms for breaches of the Act for the Restoration of Pre-War Practices, passed in August, 1919, and in only four of these were the prosecutions successful."*

The 1920-1923 wave of trade depression which passed over the engineering industry was marked by one outstanding trade dispute, in which the Engineering Employers' Federation and the Amalgamated Engineering Union played a prominent part. The Amalgamated Engineering Union, as has been said, was an outgrowth in the autumn of 1919 of the Amalgamated Society of Engineers, and resulted from an amalgamation of the latter union with six other unions,† giving a total membership of 400,000, and accumulated funds amounting to nearly 4 million sterling. Approximately three-quarters of a million other engineering workers are organized in forty-seven different trade unions divided between the Engineering and Shipbuilding Trades Federation, the National Federation of General Workers, and the National Federation of Foundry Trades. On the employers' side they are represented for purposes of negotiation with trade unions by the Engineering Employers' Federation, which includes more than 2,500 firms. It was formed in 1890 by an amalgamation of Employers' Associations

* Shadwell, *Engineering Industry*, 42.

† The six unions were The Steam Engine Makers' Society, The United Machine Workers' Association, The United Kingdom Society of Amalgamated Smiths and Strikers, The [illegible]' and Coppersmiths' Society, The North of England Brass Turners' Society, and the London United Metal Turners, Fitters, and Turners, having an aggregate membership of 70,000.

in the Glasgow district, north-east coast, Belfast and Barrow. It was not until 1897 that the London firms joined. The Federation was strengthened some time ago by its union with the National Employers' Federation, composed chiefly of firms in the Birmingham district. The voting power of members of the Federation is on the basis of their wages bill. As already noted, since the termination of the National Agreement of 1907 there was no one agreement covering the general relationship between, and defining the sphere of action of, the employers and trade unions. Numerous agreements had, however, been entered into on special subjects, and one of these, completed in 1920, related to the working of overtime and night-shifts. Notwithstanding that this agreement had been confirmed by the vote of the members of the Amalgamated Engineering Union early in 1921, an embargo was placed on the working of overtime by officials of the A.E.U., who at this period were suggesting that overtime should not be worked without the prior consent of representatives of the union. A letter of complaint, dated April 7, 1921, was addressed by the Engineering Employers' Federation to the Amalgamated Engineering Union, dealing not only with the question of overtime, but with matters relating to apprentices and the manning of machines. This letter concluded with the lock-out threat "that until the position above referred to is put right the employers will be compelled to dispense with the services of your union." Although the general vote of the members of the A.E.U. supported the action of their executive committee in resisting the employers' threat, the lock-out was not put into effect, and another conference was held in June on the question of overtime, but was adjourned until November. "This leisurely procedure, which left ample time for consideration, shows no desire to force the issue or precipitate a conflict."*

As a result of the November Conference the memorandum relating to "Managerial Functions" and overtime, drafted by the Employers' Federation, was accepted by the executive committee on ratification by the members of the A.E.U. Despite the recommendation for acceptance by the executive council the ballot of members rejected the proposals. The

* Shadwell, *The Engineering Industry*, 54.

result was that the employers gave notice of the lock-out to begin after March 11, at the same time intimating that "the relations between employers and their workpeople, working conditions and wages, would require to be brought under review," in order in the national interest to "place the industry on a sound economic basis." After the lock-out of the A.E.U. members commenced, the employers communicated with the other unions whose members were employed in engineering works, stating that now that the A.E.U. had challenged the "leading principle of control" it was necessary to know the policy of other unions in this matter, and they were asked to sign the memorandum rejected by the A.E.U. This they refused to do, and the other unions' members were consequently locked out as from May 2. Under the Industrial Disputes Act a Court of Inquiry was appointed by the Ministry of Labour on April 27 to investigate the situation, and it reported on May 10. The findings of the Court in the first place "conceded to the employer the right to decide when overtime is necessary and to use his discretion freely up to the limit of 30 hours in four weeks, but indicates that objection may be raised beyond that limit, and consequently conceded to workmen or their representatives the right to prior consultation on any proposed change in working conditions, but failing agreement allows the employer to introduce the change pending further discussion."* Following the finding of the Court, negotiations between the employers and the unions were resumed, and ultimately resulted in an agreement being reached dated June 13, 1922,† which can be regarded as a charter defining the relationship between employers and the trade unions; it makes provision for dealing with questions as they arise and provisions for avoiding disputes; the position of shop stewards and works committees are also defined, and in so far as the A.E.U. is concerned the contentious Clause J of the 1920 Overtime and Night-Shift Agreement is interpreted so that "the employers have the right to decide when overtime is necessary, the workpeople or their representatives being entitled to bring forward under the Provisions for Avoiding Disputes any cases of overtime they desire discussed. Meantime the overtime required shall be proceeded with."

* *Ibid.*, 59. † See Appendix I.

APPENDIX I

MEMORANDUM OF AGREEMENT BETWEEN THE ENGINEERING AND THE NATIONAL EMPLOYERS' FEDERATIONS AND THE AMALGAMATED ENGINEERING UNION*

DATED JUNE 13, 1922

I.—GENERAL PRINCIPLES

(*a*) The Employers have the right to manage their establishments and the Trade Unions have the right to exercise their functions.

(*b*) In the process of evolution, provision for changes in shop conditions is necessary, but it is not the intention to create any specially favoured class of workpeople.

II.—PROCEDURE FOR DEALING WITH QUESTIONS ARISING

1. GENERAL

(*a*) The procedure of the Provision for Avoiding Disputes so far as appropriate applies to:

(i) General alteration in wages;
(ii) Alterations in working conditions which are the subject of agreements officially entered into;
(iii) Alterations in the general working week;

but such alterations shall not be given effect to until the appropriate procedure between the Federations and the Trade Union or Unions concerned has been exhausted.

(*b*) Where any alteration in the recognized working conditions, other than specified in Clause (ii) 1 (*a*) hereof, contemplated by the Management will result in one class of workpeople being replaced by another in the establishment, the Management shall, unless the circumstances arising are beyond their control, give the workpeople

* With the exception of the last clause relating to Overtime and Night-shift Agreement (which is entirely left out of the other agreements), this Agreement is identical with the Agreement made with the unions affiliated to the Engineering and Shipbuilding Trades Federation, dated June 2, 1922, unions affiliated to the National Federation of General Workers, dated June 2, 1922, United Operative Spindle and Fly Makers Trade and Friendly Society, dated June 2, 1922, and the National Union of Foundry Workers, dated June 13, 1922.

directly concerned, or their representatives in the shop, not less than 10 days' intimation of their intention and afford an opportunity for discussing, if discussion is desired, with a deputation of the workpeople concerned, and/or their representatives in the shop. Should a discussion not be desired, the instructions of the Management shall be observed and work shall proceed in accordance therewith. Should a discussion take place, and no settlement be reached at the various stages of procedure which are possible within the time available, the Management shall, on the date intimated, give a temporary decision upon which work shall proceed pending the recognized procedure being carried through. The decision shall not be prejudicial to either party in any subsequent discussion which may take place.

(*c*) Where any class of workpeople is displaced by reason of any act of the Management, consideration shall be given to the case of workpeople so displaced with a view, if practicable, of affording them in the establishment work suitable to their qualifications.

(*d*) Questions arising which do not result in one class of workpeople being replaced by another in the establishment and on which discussion is desired, shall be dealt with in accordance with the Provisions for Avoiding Disputes, and work shall proceed meantime under the conditions following the act of the Management.

(*e*) Where a change is made by the Management involving questions of money payments, and as a result of negotiations in accordance with the recognized procedure it is agreed that the claim of the workpeople is established, the decision so arrived at may be made retrospective on the particular claim to a date to be mutually agreed upon, but not beyond the date upon which the question was raised.

(*f*) Where any local Agreement conflicts with the terms of this Agreement, the provisions of this Agreement shall apply.

(*g*) Nothing in the foregoing shall affect the usual practice in connection with the termination of employment of individual workpeople.

2. Provisions for Avoiding Disputes

(*a*) When a question arises, an endeavour shall be made by the Management and the workmen directly concerned to settle the same in the works or at the place where the question has arisen.

Failing settlement deputations of workmen, who may be accompanied by their Organizer (in which event a representative of the Employers' Association shall also be present), shall be received by Employers by appointment without unreasonable delay for the

mutual discussion of any question in the settlement of which both parties are directly concerned. In the event of no settlement being arrived at, it shall be competent for either party to bring the question before a Local Conference to be held between the Local Association and the Local representative of the Society.

(*b*) In the event of either party desiring to raise any question a Local Conference for this purpose may be arranged by application to the Secretary of the Local Association or the Local Representative of the Society.

(*c*) Local Conferences shall be held within seven working days, unless otherwise mutually agreed upon, from the receipt of the application by the Secretary of the Local Association, or the local representative of the Society.

(*d*) Failing settlement at a Local Conference of any question brought before it, it shall be competent for either party to refer the matter to a joint Central Conference which, if thought desirable, may make a joint recommendation to the constituent bodies.

(*e*) Central Conference shall be held on the second Friday of each month, at which questions referred to Central Conference prior to fourteen days of that date shall be taken.

(*f*) Until the procedure provided above has been carried through, there shall be no stoppage of work either of a partial or a general character.

3. Shop Stewards and Works Committee Agreement

With a view to amplifying the provisions for avoiding disputes by a recognition of Shop Stewards and the institution of Works Committees

IT IS AGREED AS FOLLOWS:

(*a*) Appointment of Shop Stewards

1. Workers, members of the above-named Trade Unions, employed in a Federated Establishment may have representatives appointed from the members of the Unions employed in the establishment to act on their behalf in accordance with the terms of this Agreement.

2. The representatives shall be known as Shop Stewards.

3. The appointment of such Shop Stewards shall be determined by the Trade Unions concerned and each Trade Union party to this Agreement may have such Shop Stewards.

4. The names of the Shop Stewards and the shop or portion of a shop in which they are employed and the Trade Union to which they belong shall be intimated officially by the Trade Union concerned to the Management on election.

(b) Appointment of Works Committees

5. A Works Committee may be set up in each establishment consisting of not more than seven representatives of the Management and not more than seven Shop Stewards, who should be representative of the various classes of workpeople employed in the establishment. The Shop Stewards elected to the Works Committee shall, subject to re-election, hold office for not more than twelve months.

6. If a question failing to be dealt with by the Works Committee, in accordance with the procedure hereinafter laid down, arises in a department which has not a Shop Steward on the Works Committee, the Works Committee may as regard the question co-opt a Shop Steward from the Department concerned. An Agenda of the points to be discussed by the Works Committee shall be issued at least three days before the date of the meeting if possible.

(c) Functions and Procedure

7. The functions of Shop Stewards and Works Committees, so far as they are concerned in the avoidance of disputes, shall be exercised in accordance with the following procedure:

(a) A worker or workers desiring to raise any question in which they are directly concerned, shall, in the first instance, discuss the same with their foremen.

(b) Failing settlement the question shall be taken up with the Shop Manager and/or Head Shop Foreman by the appropriate Shop Steward and one of the workers directly concerned.

(c) If no settlement is arrived at the question may, at the request of either party, be further considered at a meeting of the Works Committee. At this meeting the O.D.D. (Organizing District Delegate) may be present, in which event a representative of the Employers' Association shall also be present.

(d) Any question arising which affects more than one branch of trade or more than one department of the Works may be referred to the Works Committee.

(e) The question may therefore be referred for further consideration in terms of the Provisions of Avoiding Disputes.

(f) No stoppage of work shall take place until the question has been fully dealt with in accordance with this Agreement and with the "Provisions for Avoiding Disputes."

(*d*) General

8. Shop Stewards shall be subject to the control of the Trade Unions and shall act in accordance with the Rules and Regulations of the Trade Unions and agreements with employers so far as these affect the relation between employers and workpeople.

9. In connection with this Agreement, Shop Stewards shall be afforded facilities to deal with questions raised in the shops or portion of a shop in which they are employed. Shop Stewards elected to the Works Committee shall be afforded similar facilities in connection with their duties, and in the course of dealing with these questions they may, with the previous consent of the Management (such consent not to be unreasonably withheld) visit any shop or portion of a shop in the establishment. In all other respects Shop Stewards shall conform to the same working conditions as their fellow-workers.

10. Negotiations under this Agreement may be instituted either by the Management or by the workers concerned.

11. Employers and Shop Stewards and Works Committees shall not be entitled to enter into any Agreement inconsistent with agreements between the Federation or Local Association and the Trade Unions.

12. For the purpose of this Agreement the expression "establishment" shall mean the whole establishment or sections thereof according to whether the Management is unified or subdivided.

13. Any question which may arise out of the operation of this Agreement shall be brought before the Executive of the Trade Union concerned or the Federations as the case may be.

III.—OVERTIME AND NIGHT-SHIFT AGREEMENT—29th and 30th September, 1920

Interpretation of Clause J

It is agreed that in terms of the Overtime and Nightshift Agreement of 29th and 30th September, 1920, the Employers have the right to decide when overtime is necessary, the workpeople or their representatives being entitled to bring forward under the Provisions for Avoiding Disputes any cases of overtime they desire discussed. Meantime, the overtime required should be proceeded with.

Signed on behalf of—

The Engineering and the National Employers' Federations.	Allan M. Smith, *Chairman.* James Brown, *Secretary.*
The Amalgamated Engineering Union.	J. T. Brownlie, *Chairman.* A. H. Smethurst, *Secretary.*

APPENDIX II

BIBLIOGRAPHY

Very frequent use has been made of certain works, and the authors desire to record the valuable help obtained from Smiles, "*Lives of the Engineers*"; Hallock and Wade, "*The Evolution of Weights and Measures*"; *and* Pratt, "*The History of Inland Transport and Communication in England.*" *Frequent use has also been made of State Papers and Transactions of Societies.*

Chapter I.

Austen, H. H. G.: *Journal of the Anthropological Institute.* London, 1872, I. 127.

Avebury, J. L.: *Prehistoric Times.*

Babelon, E.: *Manual of Oriental Antiquities.*

Breasted, J. H.: *History of Egypt.*

British Museum Guides: (i.) *Bronze Age;* (ii.) *Early Iron Age;* (iii.) *Stone Age.*

Brugsch, H.: *Egypt under the Pharaohs.*

Budge, E. A. T. W.: *History of the Egyptian People.*

Dennis, G.: *Cities and Cemeteries of Etruria.*

Hopf, W.: *The Human Species.*

Jeans, J. S.: *History of the Iron and Steel Industry.*

King, J.: *Cleopatra's Needle.*

Mason, O. T.: *Origins of Invention.*

Maspero, G. C. C.: *Egyptian Archæology.*

Petrie, Flinders: *The Pyramids and Temples of Gizeh.*

Smith, J.: *Panorama of Science and Art.*

Turner, T.: *Metallurgy of Iron.*

Vitruvius, M.: *The Ten Books on Architecture.*

Watkins, J. E.: "Beginnings of Engineering," *Transactions of the American Society* [illegible] 1891.

Wells, H. G.: *Outline of History.*

Chapter II

Airy, G. B.: "Account of the Construction of the New National Standards of Length, and of its Principal Copies," *Philosophical Transactions,* 1857.

Hallock, W., and Wade, H. T.: *The Evolution of Weights and Measures.*

Jeans, W. T.: *Creators of the Age of Steel.*

Kelly, P.: *Metrology.*

Napier, J. R.: *British Weights and Measures.*

Nicholson, E.: *Men and Measures, A History of Weights and Measures.*

PIERCE, R. M.: *Problems of Measures.*
RIDGWAY, W.: *Origin of Weight Standards.*
SIEMENS, A.: "Metrical System of Weights and Measures," *Proceedings of the Institution of Electrical Engineers,* 1903.
WARREN, C.: *Early Weights and Measures.*
WARREN, C.: *Our Measures and the Ancient Cubit.*
WATSON, C. M.: *British Measures as Described in the Laws of England.*

CHAPTER III

BAINES, T.: *History of Liverpool.*
BESANT, W.: *History of London.*
CUNNINGHAM, B.: *Harbour Engineering.*
GLOVER, F. R. A.: *Harbours of Refuge.*
GREEN, W.: *Liverpool Docks Scheme.*
HARCOURT, L. F. V.: *Docks and Harbours.*
HEARNSHAW, J. J. C.: *History of Southampton.*
KIRKALDY, A. W.: *British Shipping: Its History, Organization, and Importance.*
MARWICK, J. D. E.: *Early History of Glasgow.*
McCARTHY, J.: *London and the Thames.*
MUIR, J. R. B.: *History of Liverpool.*
M'URE, J.: *History of Glasgow.*
OWEN, E.: *History, Working, and National Importance of Docks.*
OWEN, E.: *Industrial Rivers of the Kingdom.*
OWEN, E.: *London as a Port.*
SIMONIN, C.: *Port of Glasgow.*
SIMONIN, C.: *Port of London.*
SMILES, S.: *Lives of the Engineers.*
STEVENSON, T.: *Lighthouses.*
STUDER, P.: *Southampton, Port Books.*
TALBOT, F. A.: *Lightships and Lighthouses.*
WELLS, C.: *The Port of Bristol.*

CHAPTER IV

Royal Commission on Canals and Waterways, Fourth and Final Report, 1909.
AIKEN, J.: *A Description of the Country from Thirty to Forty Miles Round Manchester.*
BAINES, T.: *History of Liverpool.*
BAINES, T.: *Lancashire and Cheshire, Past and Present.*
BRADSHAW'S *Canals and Navigable Rivers of England and Wales.*
FLETCHER, A. W.: *Economic Results of Manchester Ship Canal.*
FORBES, W. P., AND ASHFORD: *Our Waterways.*
FULTON, H. H.: *A Treatise on the Improvement of Canal Navigation.*
HEPBURN, A. B.: *Artificial Waterways and Commercial Developments.*
JEANS, J. S.: *Waterways and Water Transport.*
JESSOP, W.: *Our Inland Navigation and Public Roads.*
LEECH, B.: *History of Manchester Ship Canal.*

LEECH, B.: *Our Canals and Waterways.*
MACPHERSON, D.: *Annals of Commerce.*
PALMER, J. E.: *British Canals.*
PHILLIPS, J.: *A General History of Inland Navigation.*
PRATT, E. A.: *A History of Inland Transport and Communication in England.*
WALMSLEY, C.: *History of Manchester Ship Canal.*
WHITWORTH, R.: *Advantages of Inland Navigation.*
YARRANTON, A.: *England's Improvements by Land and Sea.*
YOUNG, A.: *A Six Months' Tour through the North of England.* A cursory view of the advantages of an intended canal from Chesterfield to Gainsborough, 1769.

CHAPTER V

BAKER, I. O.: *A Treatise on Roads and Pavements.*
CUNNINGHAM, W.: *Growth of English Industry and Commerce.*
DEFOE, D.: *A Tour through the Whole Island of Great Britain*, 1724.
DELANY, W. K.: *The General Turn-Pike Acts.*
GILLESPIE, W. M.: *A Manual of Road Making.*
HARPER, C. G.: *The Holyhead Road.*
HAWKINS, J.: *Observations on the State of the Highways.*
HOMER, H.: *An Enquiry into the Means of Preserving Public Roads.*
JUSSERAND, J. A. A. J.: *English Wayfaring Life in the Middle Ages.*
LARDNER, D.: *Railway Economy.*
MACADAM, J. L.: *Remarks on the Present System of Road-Making.*
MACPHERSON, D.: *Annals of Commerce.*
MERITON, G.: *A Guide to the Surveyors of the Highways.*
PARNELL, H. B.: *A Treatise on Roads.*
PRATT, E. A.: *A History of Inland Transport and Communication in England.*
RICKMAN, J.: *The Life of Thomas Telford, Civil Engineer*, written by himself, edited by Rickman.
SCOTT, J.: *Digests of the General Highway and Turn-Pike Laws.*
SPEARMAN, R. H.: *The Law of Highways.*
WEBB, S. AND B.: *English Local Government.*—V. "The King's Highway."
WEBB, S. AND B.: *The Manor and the Borough.*
WELCH, C.: *History of London Bridges.*
WHITAKER, T. D.: *Loides and Elmete.*
YOUNG, A.: *A Six Months' Tour through the North of England.*
YOUNG, A.: *A Six Weeks' Tour through the Southern Counties of England and Wales.*

CHAPTER VI

ARAGO, D. F.: *Life of Watt.*
CARNEGIE, A.: *Life of Watt.*
DUNN, M.: *Coal Trade.*
EDMONDS, R.: *Memoir of Richard Trevithick.*
FAREY, J.: *The Steam Engine.*
GALLOWAY, E.: *History and Progress of the Steam Engine.*
GALLOWAY, R. L.: *Annals of Coal Mining.*

Grant, J. W.: *James Watt and the Steam Engine.*
Hart, R.: "Reminiscences of James Watt," *Transactions of the Glasgow Archæological Society*, 1859.
Lidstone, T.: *Notes on Newcomen's Steam Engine.*
Muirhead, J. P.: *Origin and Progress of the Mechanical Invention of James Watt.*
Robison, J.: *Mechanical Philosophy.*
Thurston, R. H.: *History of the Steam Engine.*
Trevithick, F.: *Life of Richard Trevithick.*
Wood, H. T.: *Industrial Engineering in the Eighteenth Century.*

Chapter VII

Bailey, J.: *General View of the Agriculture of the County of Durham.*
Baines, T.: *History of Liverpool.*
Brunlees, J.: Presidential Address, *British Association (Mechanical Science Section)*, 1883.
Buckles, W.: "The Inventions and the Life of William Murdock" in *Proceedings of the Institution of Mechanical Engineers*, 1850.
Clifford, F.: *History of Private Bill Legislation.*
Cooke, C. J. B.: *British Locomotives.*
Fraser, J.: *British Railways.*
Hunt, C.: *History of the Introduction of Gas Lighting.*
Jackman, W. T.: *Transportation in Modern England.*
Lardner, D.: *Railway Economy.*
Lawson, W. R.: *British Railways.*
Muirhead, J. P.: *The Origin and Progress of the Mechanical Invention of James Watt.*
Pease, E.: *Diaries of Edward Pease.*
Pratt, E. A.: *A History of Inland Transport and Communication in England.*
Protheroe, E.: *Railways of the World.*
Sekon, G. A.: *Evolution of the Steam Locomotive.*
Steel, W. C.: *History of the London and North-Western Railway.*
Stretton, C. E.: *History of the Liverpool and Manchester Railway.*
Stretton, C. E.: *History of London and Birmingham Railway.*
Wood, N.: *Practical Treatise on Railways.*
Young, A.: *A Six Months' Tour through the North of England.*

Chapter VIII

Bessemer, H.: *Autobiography.*
Campion, A.: Presidential Address, Scottish Branch, *Proceedings of the British Foundrymen's Association*, 1913 to 1914, 145.
Fell, A.: *Early Iron Industry of Furness.*
Gibbins, H. de B.: *Industrial History of England.*
Harbord, F. W., and Hall, J. W.: *Metallurgy of Steel.*
Jeans, J. S.: *History of the Iron and Steel Industry.*
Jeans, J. S.: *Iron Trade of Great Britain.*
Jeans, W. T.: *Creators of the Age of Steel.*

LANGE, *Bessemer, Goransson, and Mushet.*
MOLDENKE, R.: *Principles of Iron Founding.*
PERCY, J.: *Metallurgy, Iron, and Steel.*
SALZMAN, L. F.: *Industries of the Middle Ages.*
SCRIVENOR, H.: *History of the Iron Trade.*
SMILES, S.: *Industrial Biography.*
STANSBIE, J. H.: *Iron and Steel.*
TURNER, T.: *Metallurgy of Iron.*

CHAPTER IX

BEAUMONT, W. W.: *Motor Vehicles and Motors.*
BERRIMAN, A. E.: *Aviation.*
BERRIMAN, A. E.: *British Aircraft Industry.*
CARPENTER, R. C., AND DIEDERICHS, H.: *Internal Combustion Engines.*
CRESSY, E.: *Outline of Industrial History of England.*
DIXON, H. B.: *Domestic Use of Gas.*
GRAHAM WHITE AND HARPER, H.: *Air Power.*
HUNT, C.: *A History of the Introduction of Gas Lighting.*
MATTHEWS, W.: *Historical Sketch of the Origin, Progress, and Present State of Gas Lighting.*
MURDOCK, A.: *A Century of Gas Lighting.*
NEWBIGGING, T.: *Hundred Years of Gas Enterprise.*
PRATT, E. A.: *History of Inland Transport and Communication in England.*
WYATT, H.: *The Motor Industry.*
YOUNG, A. B. F.: *Complete Motorist.*

CHAPTER X

Commemoration Number, *Journal of the Institution of Electrical Engineers*, 1922. Electric Lighting Undertakings. Report of National Civic Federation.
BEAVAN, A. H.: *Tube, Train, Tram, and Car.*
DAWSON, P.: *Electric Traction on Railways.*
FLEMING, J. A.: *Fifty Years of Electricity.*
GARCKE, E.: *Manual of Electrical Undertakings.*
JUDD, W.: "Submarine Telegraphy," *Journal of the Institution o Electrical Engineers*, 1922.
KINGSBURY, J. E.: *The Telephone and Telephone Exchanges: Their Invention and Development.*
LUCKIESH, M.: *Artificial Light.*
MOTTELAY, P. F.: *Bibliographical History of Electricity and Magnetism.*
PRATT, E. A.: *A History of Inland Transport and Communication in England.*
SCHUSTER, A.: *Britain's Heritage of Science.*
WHYTE, A. G.: *Electricity in Locomotion.*
WHYTE, A. G.: *The All-Electric Age.*
WHYTE, A. G.: *The Electrical Industry.*

CHAPTER XI

ARMITAGE, F.: *The Old Guilds of England.*
ASHLEY, W. J.: *Introduction to Economic History.*
BRAY, R. A.: *Boy Labour and Apprenticeship.*
CUNNINGHAM, W.: *Growth of English Industry and Commerce.*
DEARLE, N. B.: *Industrial Training.*
DEFOE, D.: *Tour through the Whole Island of Great Britain.*
DUNLOP, O. J.: *British Apprenticeship.*
FAIRBAIRN, W.: *A Treatise on Mills and Mill Work.*
FAY, C. R.: *Life and Labour in the Nineteenth Century.*
FINDLAY, J. J.: *The Young Wage-Earner.*
FLEMING, A. P. M., AND BROCKLEHURST, H. J.: *Industrial Administration.*
FLEMING, A. P. M., AND PEARCE, J. G.: *Principles of Apprentice Training.*
GIBBINS, H. DE B.: *Industrial History of England.*
GOLDMARK, J.: *Fatigue and Efficiency.*
HAMMOND, B. B.: *The Skilled Labourer.*
HAMMOND, B. B.: *The Town Labourer.*
HUTCHINS, B. L., AND HARRISON, A.: *History of Factory Legislation.*
LECKY, W. E. H.: *History of the Eighteenth Century.*
LIPSON, E.: *The History of the English Woollen and Worsted Industries.*
MACASSEY, L.: *Labour Policy.*
MYERS, C. S.: *Mind and Work.*
NICHOLSON, J. S.: *Effects of Machinery on Wages.*
PAGE, W.: *Commerce and Industry.*
PROUD, E. D.: *Welfare Work.*
SHADWELL, A.: *The Engineering Industry.*
UNWIN, G.: *Industrial Organization in the Fifteenth, Sixteenth, and Seventeenth Centuries.*
WEBB, S. AND B.: *History of Trade Unionism.*
WEBB, S. AND B.: *Industrial Democracy.*